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Statistical Model for Range Safety Analysis of Laser Hazard

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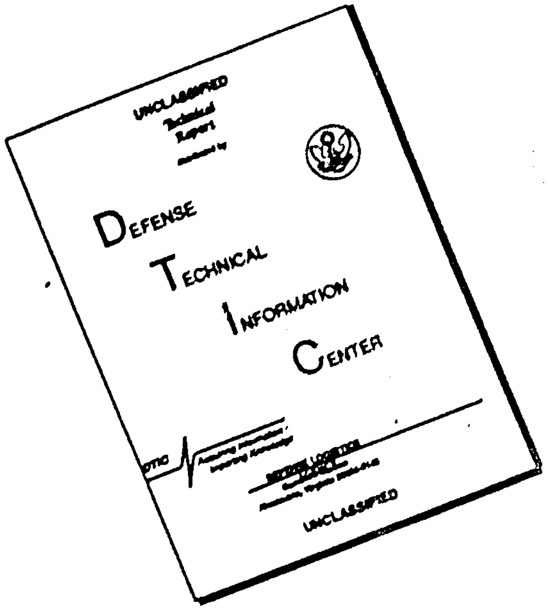

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ABSTRACT

A statistical model of a laser designator pulse train is developed. The model is applicable to the quantification of range safety hazards associated with field tests of tactical weapons which employ lasers. Numerical results of selected test cases are given.

Input variables and operating procedures for the computer programs developed to print and plot the probability of hazard data, as well as isopleths of specified probability levels, are presented in Appendix A.

An interactive safe eye distance matrix program which provides an input value for the probability model is described in Appendix B.

(Revised 12/15/80)
(Revised 03/01/82)

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FOREWORD

The work in this report was sponsored by the Range Support Division (SESR) of the Directorate of Systems Engineering and Range Support (SES) at the Armament Division (AD) under Contract No. F08635-79-C-0140 and is a deliverable item under Study Task Order No. 72-000-79-7. The work was monitored by Mr. Robert H. Thompson and Mr. Lonnie E. Owen of the Range Support Division.

The computer programs described herein, and certain pages of the report itself, were revised under Study Task Order No's SESR 80-7 (15 December 1980), SESR 81-1 (2 July 1981), and SER 81-9 (1 March 1982), and represent deliverable items for these tasks.

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1.0 INTRODUCTION

1.1 Study Objective

The use of lasers in tests of tactical weapon systems induces potential hazards to individuals in the test area. The objective of the study which is reported here is to furnish and analyze models which may be used to quantify those hazards. The emphasis of the analysis is directed toward determination of the likelihood that a point or area will be illuminated by a laser.

1.2 Background Range Safety Studies

This study is part of a series of study task orders written by AD Range Safety pursuant to the systematic development of risk assessment associated with tests of tactical weapons which utilize lasers.

1.3 Study Approach

Studies performed in the past have described the bounds of air volume and surface area which is subject to radiation, but those studies do not include estimation of the likelihood of the illumination of a point. Such a calculation requires a model for the uncertainties associated with pointing the center of the laser beam. The present study is organized to include the following:

A. Based on a literature survey, a general model of a laser designator beam was developed. The development is given in Section 3.

B. Using the results of past studies, the calculation of the probability of illumination of a given point with a pulse of energy is formulated as a geometry problem on a unit sphere

about the laser. The development is given in Section 3.2.3. The questions of (1) safe-eye-exposure distance and (2) the likelihood that a radiated individual will suffer ocular damage are separable from the question of the probability of illumination. Those questions are examined in Section 3.2.3.5.

C. The model which is developed is exercised for some particular cases. The example cases are given in Section 4.

1.4 Computer Programs Developed

The development of the mathematics leading to the determination of probability of hazardous radiation to a grid of points surrounding the target during a test period required modification of an existing computer program for verification of the statistical model. Subsequent use of the model indicated the need for enhancements in the areas of laser and target input position data, plot limit determination, and safe eye exposure distance criteria.

The imposition of these requirements on the modified program used for verification led to the development of program LPHP, the Laser Probability of Hazard Program and program SEED, a Safe Eye Exposure Distance matrix computation program.

Analysis of the risk involved in laser operation during a test period also utilizes the footprint created by an isopleth of a specified level of probability of hazardous radiation. In order to provide this footprint, in isopleth plotting program generated by a previous study was modified to be compatible with a disk file of data output by program LPHP. User specification

of the probability levels to be plotted are input variables to LPHP.

The methods of accessing and executing the three programs, as well as the input variables necessary for operation, are described in Appendices A and B.

2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 Conclusions

A. The model of the behavior of a laser designator pulse train which is formulated in Section 3 of this report is applicable to the resolution of range safety questions arising from field tests of weapons which employ laser designators.

B. The model is sufficiently general to permit its use for a variety of laser designators and rangefinders.

C. The computer programs produced for evaluation of the statistical model provide key elements of information used in the analysis of risk involved in laser usage during testing.

2.2 Recommendations

It is recommended that the software developed in this study be used to determine hazard levels associated with tests which employ lasers.

It is also recommended that program SEED be executed from a remote terminal which has printer capabilities so that the matrix of safe eye exposure distances and optical density requirements generated may be retained for future reference.

(Revised 12/15/80)

3.0 ANALYSIS

3.1 Symbolism and Nomenclature

The symbols and names which were employed in a past study are used in this report. The coordinate systems which are utilized to describe the laser cone behavior are defined in Table 3.1 below.

Table 3.1
Coordinate Systems and Associated Orthonormal Vector Sets

Coordinate Symbol	Origin with Respect to the (x,y,z) System	Orthonormal Vector Set Located at the Origin	Definitions
(x,y,z)	$(0,0,0)$	$(\bar{I},\bar{J},\bar{K})$	$(0,0,0)$ is a point on the earth surface either given or derived from given geodetic coordinates The laser is given at (x_L,y_L,z_L) and the target is given at (x_T,y_T,z_T). $\bar{I}$ is positive to the north $\bar{J}$ is positive upward $\bar{K}$ is positive to the east Position Vector: $\bar{R} = x\bar{I} + y\bar{J} + z\bar{K}$
(u,v,w)	$(x_g,0,z_g)$	$(\bar{\delta}_1,\bar{\delta}_2,\bar{\delta}_3)$	The line, ℓ_{LT}, containing L and T intersects the (x,z) plane at $(x_g,0,z_g)$. If ℓ_{LT} is parallel to (x,z) plane, then $(x_g,0,z_g) = (x_L,0,z_L)$ The plane spanned by $(\bar{\delta}_1,\bar{\delta}_2)$ contains L and T, $\bar{\delta}_1 \times \bar{\delta}_2 = \bar{\delta}_3$ and $\bar{\delta}_2 = \bar{J}$. Position Vector: $\bar{R} = u\bar{\delta}_1 + v\bar{\delta}_2 + w\bar{\delta}_3$
(μ,ν,ω)	(x_s,y_s,z_s)	$(\bar{s}_1,\bar{s}_2,\bar{s}_3)$	The reflecting plane, Π_s, contains the given point (x_s,y_s,z_s). The plane $y = y_s$ intersects Π_s along the coordinate line ω The normal to Π_s is $\bar{s}_2$; $\bar{s}_3$ lies in both $y = y_s$ and Π_s such that $\bar{s}_3 \times \bar{K} = (\sin\psi_s)\bar{J}$, $\bar{s}_1 \times \bar{s}_2 = \bar{s}_3$ and $\bar{s}_2 \times \bar{J} = (\sin\gamma_s)\bar{s}_3$. Position Vector: $\bar{R} = \mu\bar{s}_1 + \nu\bar{s}_2 + \omega\bar{s}_3$
(ξ,η,ζ)	(x_p,y_p,z_p)	$(\bar{e}_1,\bar{e}_2,\bar{e}_3)$	(x_p,y_p,z_p) is the intersection of ℓ_{LT} with Π_s If ℓ_{LT} is parallel to Π_s, $(x_p,y_p z_p)$ is the normal projection of L on Π_s. The normal to Π_s is $\bar{e}_2$; $(\bar{e}_1,\bar{e}_2)$ spans a plane containing L and T, and $\bar{e}_1 \times \bar{e}_2 = \bar{e}_3$. Position Vector: $\bar{R} = \xi\bar{e}_1 + \eta\bar{e}_2 + \zeta\bar{e}_3$
(ρ_1,ρ_2,ρ_3)	(x_L,y_L,z_L)	$(\bar{f}_1,\bar{f}_2,\bar{f}_3)$	$\bar{f}_3$ is a unit vector at the laser directed toward the target, $\bar{f}_2 = \bar{\delta}_3$, and $\bar{f}_1 \times \bar{f}_2 = \bar{f}_3$ so that $(\bar{f}_1,\bar{f}_3)$ and $(\bar{\delta}_1,\bar{\delta}_2)$ span the same plane. Position Vector: $R = \rho_1\bar{f}_1 + \rho_2\bar{f}_2 + \rho_3\bar{f}_3$

Symbols are defined as they occur in the body of the report. Some principal points, vectors and angles are identified below.

Points in the (x,y,z) coordinate system.

(x_L, y_L, z_L) is the laser location. A test description will necessarily include (x_L, y_L, z_L) as a function of time.

(x_T, y_T, z_T) is the (time dependent) target location.

(x_C, y_C, z_C) is a (time dependent) point of concern.

Vector symbolism

$\bar{R}_{ba}$ is a (general) vector to point b from point a, and the component distance $x_b - x_a$ is denoted by $x_b - x_a \equiv x_{ba}$. The length of $\bar{R}_{ba}$ is R_{ba}. In particular,

$$\begin{aligned}\bar{R}_{TL} &= (x_T - x_L)\bar{i} + (y_T - y_L)\bar{j} + (z_T - z_L)\bar{k} \\ &= x_{TL}\bar{i} + y_{TL}\bar{j} + z_{TL}\bar{k} \\ &= R_{TL}\bar{r}_3.\end{aligned}$$

Angles δ, ψ, α_m, ϕ

Let $\bar{\rho}_s$ be a unit vector at the laser with an identifying dummy subscript "s". Then the angles δ_s, ψ_s locate $\bar{\rho}_s$ according to Figure 3.1.1 below:

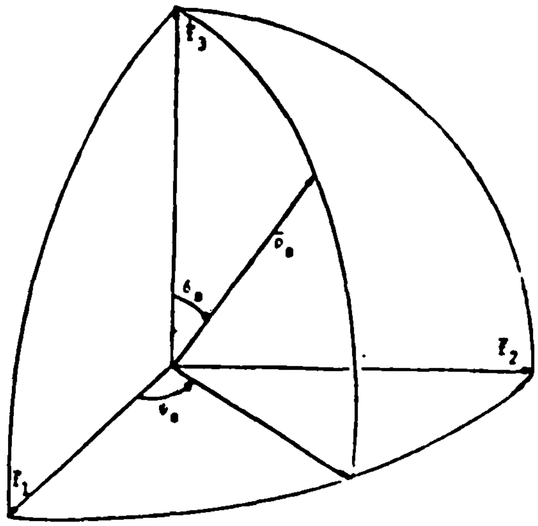


Figure 3.1.1 The Angles ψ_s, δ_s

That is,

$\bar{\rho}_s = \sin\delta_s \cos\psi_s \bar{r}_1 + \sin\delta_s \sin\psi_s \bar{r}_2 + \cos\delta_s \bar{r}_3.$

Let $\bar{\rho}_\ell$ be a unit vector at the laser positive along the centerline of the laser beam. Then α_m is the maximum angle of excursion of $\bar{\rho}_\ell$ away from $\bar{r}_3$: that is, $\bar{\rho}_\ell \cdot \bar{r}_3 \geq \cos\alpha_m$.

The angle ϕ is the laser beam divergence half-angle. If d is the initial beam diameter, then the beam diameter at range R is $(d + 2R\tan\phi)$ which for small angles is $(d + 2R\phi)$.

3.2 The Laser Beam Model

3.2.1 Problem Definition

It is assumed that the laser beam is approximated by a right circular cone with central half-angle ϕ and the $\bar{\rho}_\ell$ is a (time-dependent) unit vector from the cone apex along the cone centerline. Questions related to the laser energy density as it is influenced by atmospheric scattering and turbulence are addressed in a past study. The problem here is to model $\bar{\rho}_\ell$ to approximate a military laser designator.

3.2.2 Distribution of δ_ℓ and ψ_ℓ

The vector $\bar{\rho}_\ell$ is statistically determined. A literature search was undertaken to located $\bar{\rho}_\ell$ data. The most useful data related to characteristics of military designators and range finders were located. Those data are used as the basis for a model for the distribution of δ_ℓ and ψ_ℓ .

A summary histogram of the distribution of δ_ℓ constructed from data obtained from test missions is shown in Figure 3.2.1.1, p. 3-7. The distribution has a maximum δ_ℓ of (approximately) 2 mils, a mean of $\bar{\mu}_\ell$ = .362 mils and a standard deviation of .30 mils.

A satisfactory empirical approximation of the figure 3.2.1.1 histogram is furnished by a truncated gamma distribution. The gamma distribution is

$$f_1(\delta) = \frac{1}{\Gamma(a)b^a}\delta^{a-1}e^{-\delta/b} \qquad 0 \leq \delta < \infty \qquad 3.2.1.1$$

in which a and b are related to $\bar{\mu}$ and σ by

$$a = (\mu/\sigma)^2; \quad 1/b = \mu/\sigma^2 \qquad 3.2.1.2$$

For the particular data from a past study, (measuring δ in radians)

$$a = 1.45604$$

and 3.2.1.3

$$1/b = 4022.2$$

from which

$$(\Gamma(a)b^a)^{-1} = 2.000722 \times 10^5 \ .$$

Truncation at $\delta = .002$ radians requires a constant K_m such that

$$K_m\int_0^{.002} f_1(\delta)d\delta = 1 \qquad 3.2.1.4$$

which yields

$$K_m = 1.00272. \qquad 3.2.1.5$$

In figure 3.2.1.2, p.3-8, the density function $f(\delta) = K_m f_1(\delta)$ is overlaid on the original histogram with appropriate scale changes.

The above heuristic development furnishes a radial density. More to the point , a function $F(\delta,\psi)$ is required such that

$$\int_{\psi=0}^{2\pi}\int_{\delta=0}^{\alpha_m} F(\delta,\psi)dS = 1 \qquad 3.2.1.6$$

in which $F(\delta,\psi)$ is the density function and $dS = \sin\delta d\delta d\psi$ is the differential of area on a polar zone of a unit sphere. The data from a past study indicate that more error is introduced in the horizontal direction than in the vertical direction (i.e., the distribution of ψ is not uniform), and that the

angular tracking accuracy is a function of the range to the target. A useful idealized model may be obtained by deleting those complicating factors. Assuming a uniform distribution of ψ,

$$F(\delta,\psi) = \frac{K_m}{2\pi\Gamma(a)b^a} e^{-\delta/b}\delta^{a-2} \qquad 3.2.1.7$$

satisfies 3.2.1.6 and 3.2.1.1 (under the assumption that α_m is small).

Estimates of the maximum size of α_m are based on a previous study. Those estimates are:

α_m	Mode of Use
10 mils	hand held designator or moving platform without gyro-stabilization.
5 mils	light tripod or a moving ground vehicle
2 mils	heavy static base or an aircraft with a stable platform

Using equations 3.2.1.1 and 3.2.1.2 and assuming that the particular model developed above is characteristic of laser designators, one obtains the general model

$$f(\delta) = \frac{K_m}{\Gamma(a)b^a} \delta^{a-1}e^{-\delta/b} \qquad 3.2.1.8$$

in which

$$a = 1.456 \qquad 3.2.1.9$$

$$b = .1243\alpha_m \qquad 3.2.1.10$$

and

$$1/K_m = \int_0^{\alpha_m}(\Gamma(a)b^a)^{-1}\delta^{a-1}e^{-\delta/b}d\delta \qquad 3.2.1.11$$

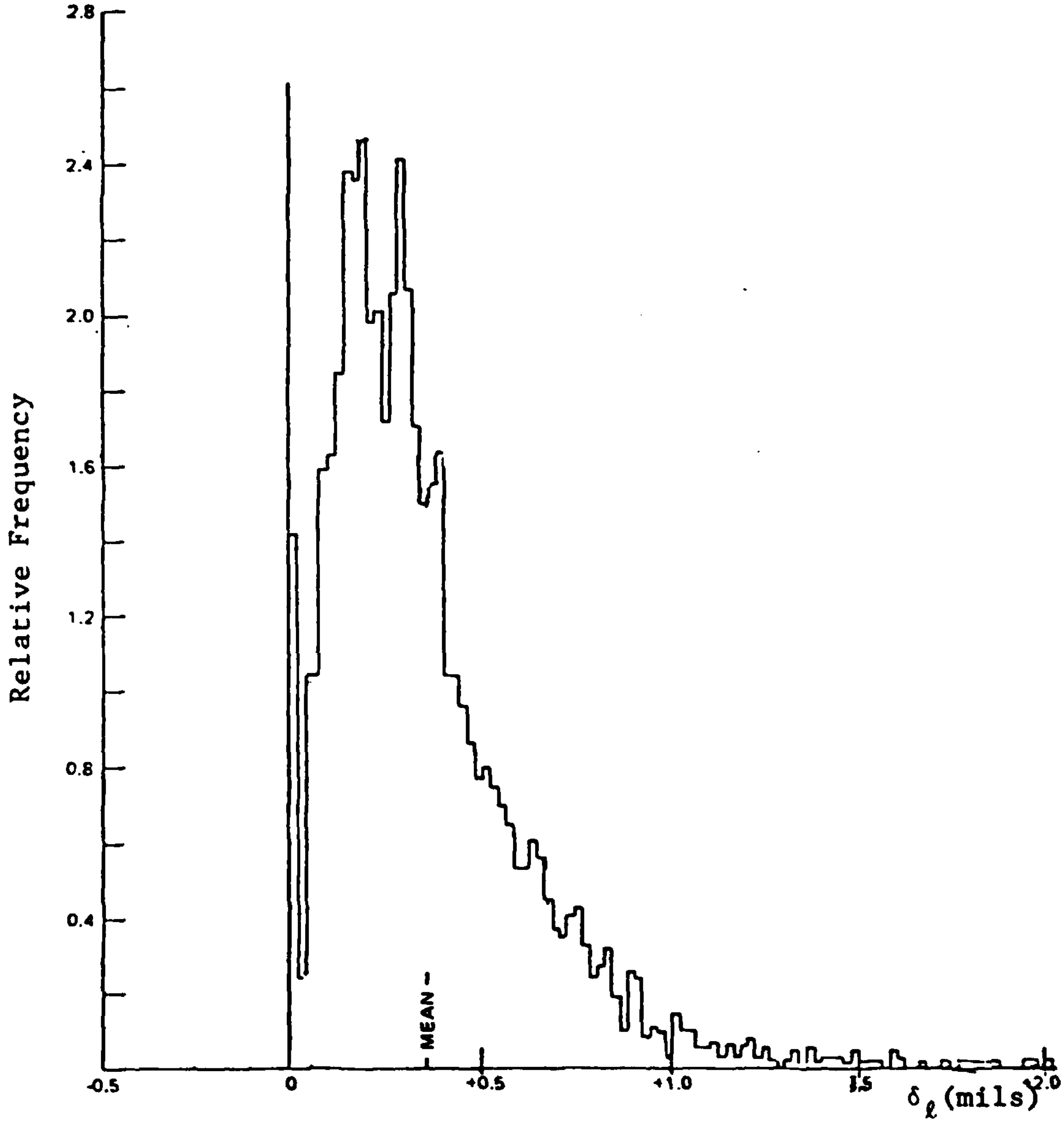


Figure 3.2.1.1 Radial Miss Angle δ_ℓ

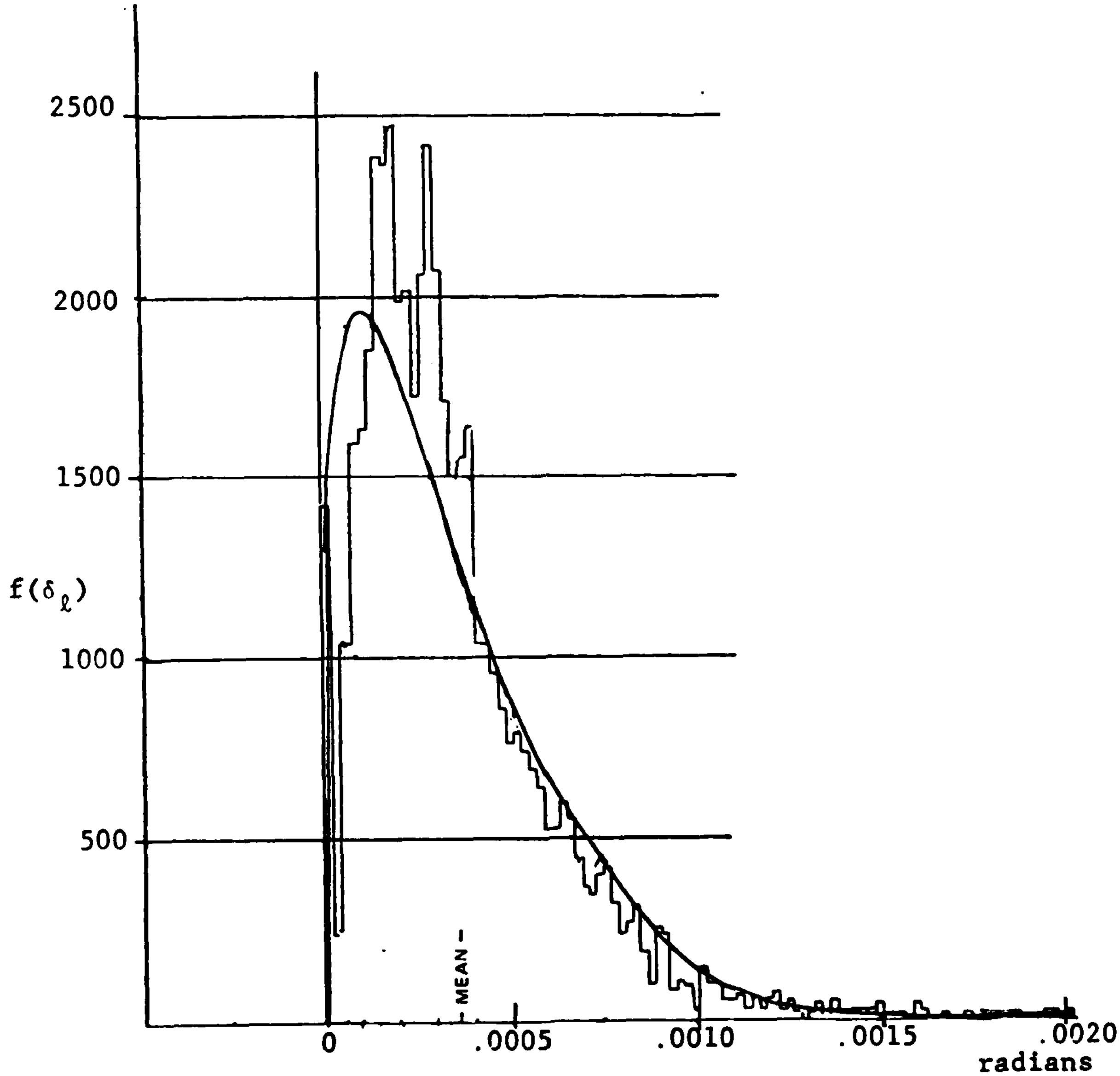


Figure 3.2.1.2 Distribution of δ_ℓ

3.2.3 Probability of Illumination

3.2.3.1 Restriction of the General Problem

The analysis of many range safety questions arising from field tests of weapons which employ laser designators can be formulated so that the central computational question is: What is the probability that a single point will be illuminated by a single pulse of a laser? Given the answer to that question, one may synthesize answers to the more general question: What is the probability that an area or volume or moving target will be illuminated during a test? The following subsection addresses the specific question.

3.2.3.2 Illumination of a Point by a Laser Pulse

The coordinate definition for

(x_L, y_L, z_L), the laser location

(x_T, y_T, z_T), the target location

(x_C, y_C, z_C), the location of a point of concern

is given in subsection 3.1.

If $\bar{\rho}_\ell$ is a unit vector along the positive axis of the laser, if $\bar{R}_{CL} = R_{CL}\bar{\rho}_C$, and if ϕ is the laser beam's half-angle divergence, then (x_C, y_C, z_C) is illuminated (by direct radiation) if

(1) $\bar{\rho}_\ell \cdot \bar{\rho}_C \geq \cos\phi$

and

(2) $R_{CL} \leq R_{seed}$

in which R_{seed} is the single pulse safe-eye-exposure-distance.

The calculation of R_{seed}, which is separate from the calculation of $\bar{\rho}_\ell \cdot \bar{\rho}_C$, is given in a previous study. It is noted that sufficient assumptions are made to assure that R_{seed} is a real variable, but $\bar{\rho}_\ell$ is a random variable.

The geometry of $\bar{\rho}_L$ and $\bar{\rho}_C$ is pictured in three figures. Figure 3.2.3.2.1, p.3-13, exhibits gross geometry relating some coordinate systems. Figure 3.2.3.2.2, p.3-14, shows some relevant minor circles on the unit sphere about the laser, and Figure 3.2.3.2.3, p.3-14, shows a section of the unit sphere for the case in which the laser cone contains the $\bar{f}_3$ axis. (The laser is treated as a point source; if it is consequential, compensation can be made for the initial laser beam diameter by moving the laser in the negative $\bar{f}_3$ direction to a virtual point source location.)

Referring to Figure 3.2.3.2.2, the probability, $P(\delta_C)$, that $\bar{\rho}_\ell \cdot \bar{\rho}_C \geq \cos\phi$ is the probability that $\bar{\rho}_\ell$ terminates in the minor circle $m_{C\phi}$. That is,

$$P(\delta_C) = \iint_S F(\delta,\psi)dS \qquad 3.2.3.1$$

in which S is the surface bounded by the minor circle $m_{C\phi}$. If spherical coordinates, ψ,δ, are used, the limits of integration for eqn. 3.2.3.1 depend on whether the pole $\bar{f}_3$ is contained in the circle $m_{C\phi}$.

Suppose $\delta_C > \phi$. Then the geometry of Figure 3.2.3.2.2 is valid and eqn. 3.2.3.1 is

$$P(\delta_C) = 2\int_{\delta_C-\phi}^{\delta_C+\phi}\int_{\psi=0}^{\Delta\psi_k} \frac{K_m e^{-\delta/b}\delta^{a-2}}{\pi\Gamma(a)b^a}\sin\delta\, d\delta\, d\psi$$

$$\simeq 2\frac{K_m}{\pi\Gamma(a)b^a}\int_{\delta_C-\phi}^{\delta_C+\phi}\Delta\psi_k e^{-\delta/b}\delta^{a-1}d\delta \qquad 3.2.3.2$$

The assumption which is made in eqn. 3.2.3.2 that $\sin\delta \simeq \delta$ is valid for the small values which α_m may assume.

To express $\Delta\psi_k$, use Figures 3.1.1 and 3.2.3.2.2:

$$\begin{aligned}\bar{\rho}_k &= \sin\delta_k\cos(\psi_C-\Delta\psi_k)\bar{f}_1+\sin\delta_k\sin(\psi_C-\Delta\psi_k)\bar{f}_2+\cos\delta_k\bar{f}_3\\ \bar{\rho}_C &= \sin\delta_C\cos\psi_C\bar{f}_1 + \sin\delta_C\sin\psi_C\bar{f}_2 + \cos\delta_C\bar{f}_3\end{aligned} \qquad 3.2.3.3$$

from which

$$\bar{\rho}_k\cdot\bar{\rho}_C = \sin\delta_k\sin\delta_C\cos\Delta\psi_k + \cos\delta_C\cos\delta_k = \cos\phi \qquad 3.2.3.4$$

or

$$\Delta\psi_k = \cos^{-1}\left(\frac{\cos\phi-\cos\delta_C\cos\delta_k}{\sin\delta_C\sin\delta_k}\right) . \qquad 3.2.3.5$$

In equation 3.2.3.5, $\Delta\psi_k$ is bounded by o and π.

The integral 3.2.1.11 was evaluated using a trapezoid rule with a Hewlett-Packard 65, and it was found that an integration step of $\alpha_m/200$ is sufficiently fine.

Let n_1 be an integer such that

$$n_1 \geq \frac{2\phi}{\alpha_m}(200) \qquad 3.2.3.6$$

then, eqn. 3.2.3.2 is approximated by

$$\frac{2\phi K_m}{\pi\Gamma(a)b^a n_1}\sum_{k=1}^{n_1}\Delta\psi_k e^{-\delta_k/b}\delta_k^{a-1} \qquad 3.2.3.7$$

in which $\delta_k = \delta_c + \phi(1-\frac{2k-1}{n_1})$.

If $\phi>\delta_c$, the circle $m_{c\phi}$ contains the pole and the geometry of Figure 3.2.3.2.3 is used to express the integral of eqn. 3.2.3.1. In this case, choose integers n_2 and n_3 such that

$$n_2 \geq \frac{2\delta_c}{\alpha_m}(200)$$
$$n_3 \geq \frac{n_1-n_2}{2} \qquad 3.2.3.8$$

Then

$$P(\delta_c) = 2\int_{\phi-\delta_c}^{\phi+\delta_c}\int_{\psi=0}^{\psi_k}\frac{K_m e^{-\delta/b}\delta^{a-2}\sin\delta\, d\delta\, d\psi}{2\pi\Gamma(a)b^a} + \int_0^{\phi-\delta_c} K_m\frac{e^{-\delta/b}\delta^{a-1}d\delta}{\Gamma(a)b^a}$$

3.2.3.9

can be approximated by

$$P(\delta_c) = \frac{2\delta_c K_m}{n_2\pi\Gamma(a)b^a}\sum_{k=1}^{n_2}\Delta\psi_k e^{-\delta_k/b}\delta_k^{a-1} + \frac{dK_m}{\Gamma(a)b^a}\sum_{k=1}^{n_3}(kd)^{a-1}e^{-kd/b}$$

3.2.3.10

in which $\delta_k = \phi+\delta_c(1-\frac{2k-1}{n_2})$ and $d = \frac{\phi-\delta_c}{n_3}$.

If $\delta_c = 0$, the first term of eqn. 3.2.3.10 disappears and

$$P(\delta_c) = \frac{dK_m}{\Gamma(a)b^a}\sum_{k=1}^{n_3}(kd)^{a-1}e^{-(kd)/b} \qquad 3.2.3.11$$

in which $\quad d = \frac{\phi-\delta_c}{n_3} = \frac{\phi}{n_3}$.

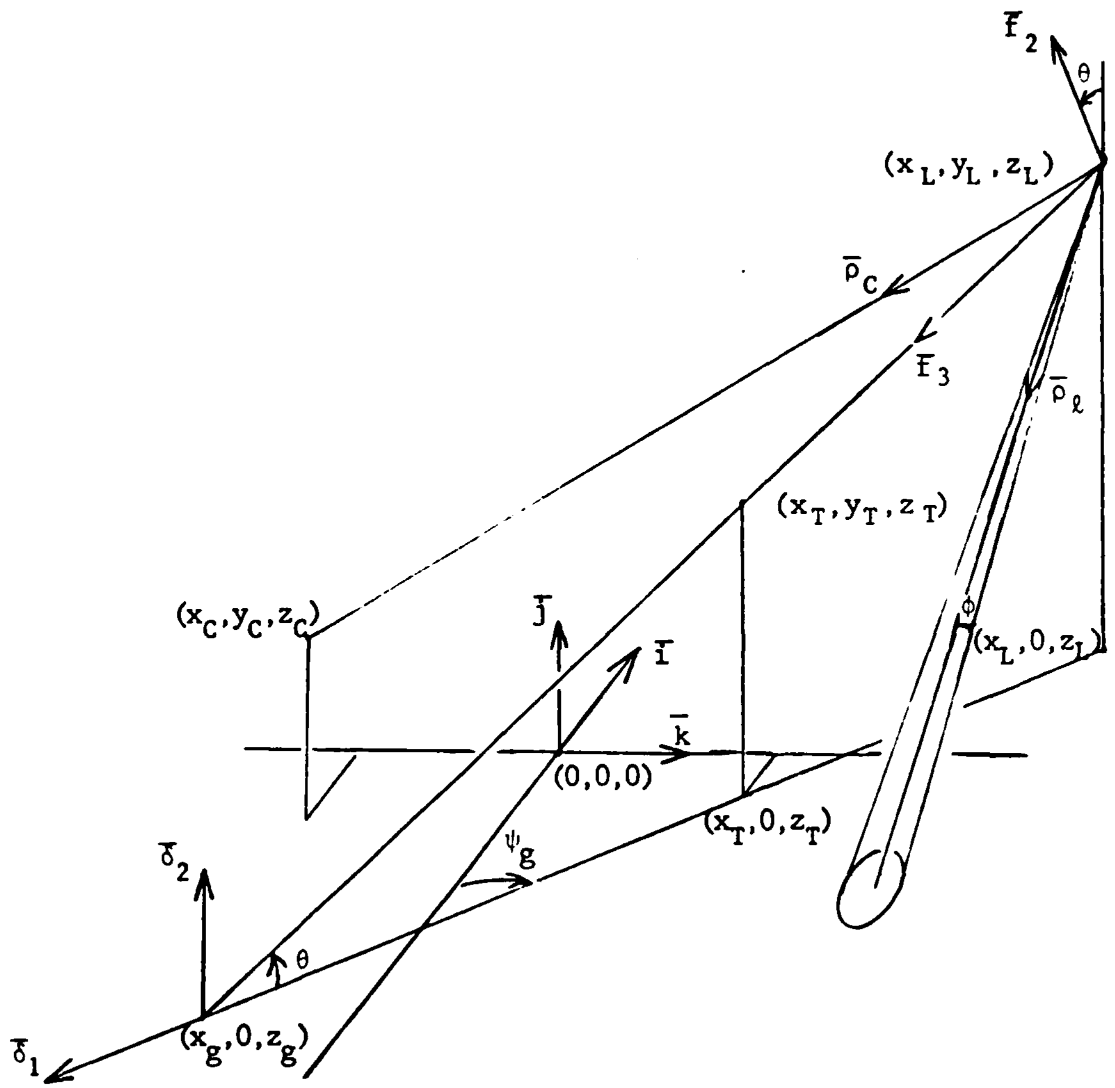


Figure 3.2.3.2.1 Gross Geometry

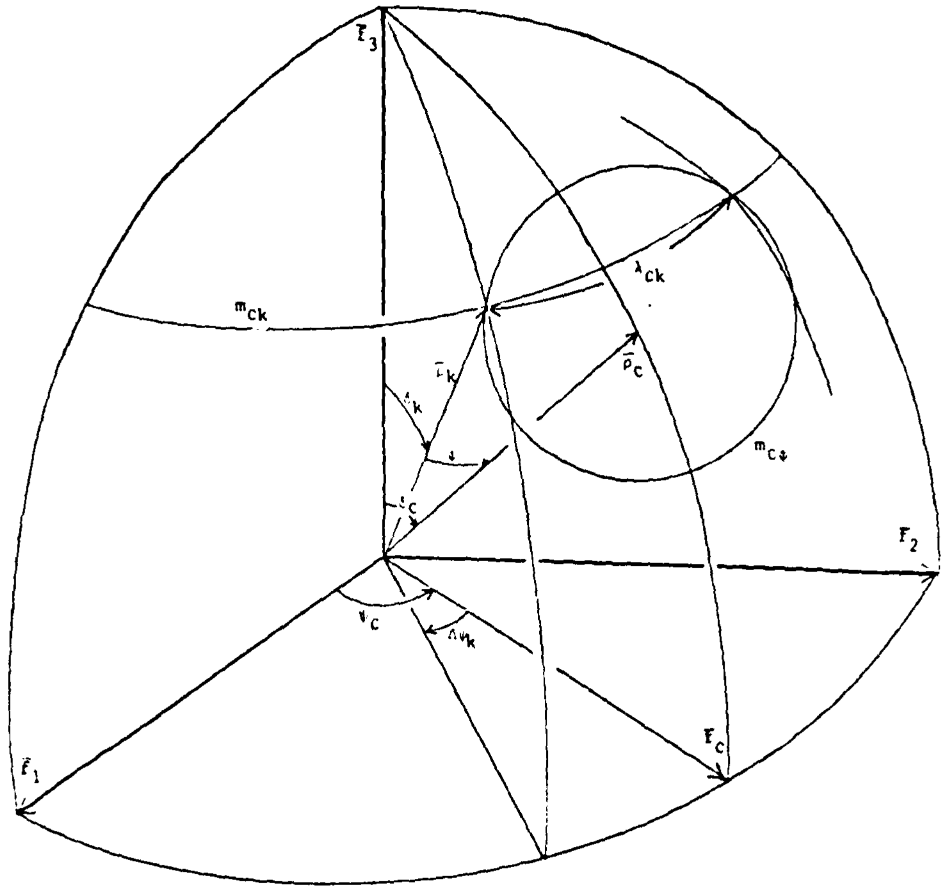


Figure 3.2.3.2.2 Minor Circles on a Unit Sphere

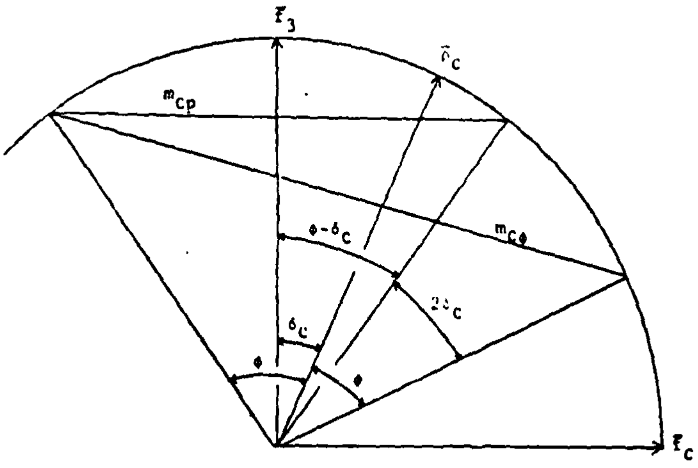


Figure 3.2.3.2.3 Section of a Unit Sphere

3.2.3.3 Formula Summary

The formulas developed in section 3.2.3.2 and shown by the flow diagram on page 4-3 are collected below:

If $\bar{R}_{CL} = R_{CL}\bar{\rho}_C$ and $\bar{\rho}_C \cdot \bar{r}_3 = \cos\delta_C$, then the probability $P(\delta_C)$ that (x_C, y_C, z_C) is illuminated by a single laser pulse is calculated as follows:

(1) Laser characteristics α_m and ϕ are given.

(2) Integers n_1, n_2, n_3 are determined such that

$n_1 \geq 400\phi/\alpha_m$; $n_2 \geq 400\delta_C/\alpha_m$; $n_3 \geq (n_1 - n_2)/2$

(3) Constants a, b, d, K_m and Ω are determined according to $a \equiv 1.456$; $b \equiv 1.243\alpha_m$; $d \equiv (\phi - \delta_C)/n_3$

$$(K_m)^{-1} \equiv \int_0^{\alpha_m} \frac{1}{\Gamma(a)b^a} \delta^{a-1} \exp(-\delta/b)\,d\delta \quad ; \quad \Omega \equiv K_m/\Gamma(a)b^a$$

(4) Functions of the index k and the parameter δ_k are defined according to

$$\Delta\psi_k \equiv \cos^{-1}((\cos\phi - \cos\delta_C\cos\delta_k)/\sin\delta_C\sin\delta_k)$$

$$H_k \equiv (\Delta\psi_k)\delta_k^{a-1}\exp(-\delta_k/b)$$

$$G_k \equiv (kd)^{a-1}\exp(-kd/b)$$

(5) $P(\delta_C)$ is determined by the formulas:

(a) If $\delta_C > \phi$, $P(\delta_C) = (2\phi\Omega/\pi n_1) \sum_{k=1}^{n_1} H_k$

in which $\delta_k = \delta_C + \phi(1 - (2k-1)/n_1)$.

(b) If $\phi > \delta_C > 0$,

$$P(\delta_C) = (2\delta_C\Omega/\pi n_2) \sum_{k=1}^{n_2} H_k + d\Omega\sum_{k=1}^{n_3} G_k$$

in which $\delta_k = \phi + \delta_C(1 - (2k-1)/n_2)$.

(c) If $\delta_C = 0$,

$$P(\delta_C) = d\Omega\sum_{k=1}^{n_3} G_k \ .$$

3.2.3.4 Illumination of a Point During a Test

A typical laser designator may have a pulse width of 2×10^{-8} seconds and a pulse frequency of 10 pulses per second. It is probable that the location of the laser cone centerline at the time of a single pulse is correlated with its location at the time of the previous pulse. However, one may argue, empirically, that the correlation is weak. Observation of a laser spotlight located kilometer distances from the source reveals a high frequency jitter about the target point. Part of this jitter results from air turbulence and cannot be removed by stabilization of the laser platform. Thus, together with other idealizing characteristics of the model, it is assumed that the location of pulse images in a pulse train are not correlated.

Suppose that a test plan is furnished in a form so that the locations of the laser, the target and the point of concern are given as functions of time. If the laser is active from time t_1 to time t_N and the pulse frequency is 10 pulses per second, then the point of concern is potentially subject to illumination $N = 10(t_N-t_1)$ times: say, $t_1, t_2, \ldots, t_i, \ldots, t_N$. If $P(\delta_{Ci})$ is the probability that $(x_C(t_i), y_C(t_i), z_C(t_i))$ is illuminated at time t_i, then the probability, P_C, that the point of concern is illuminated at least once during the test is

$$P_C = 1-\prod_{i=1}^{N}(1-P(\delta_{Ci})) \quad . \qquad 3.2.3.4.1$$

3.2.3.5 Conditional Probability of Ocular Damage

No statistics were located concerning the likelihood that individuals who are illuminated will be oriented to receive and focus the pulse of radiation. From a range safety point of view (until a more convincing model is developed), it is prudent to assume that a test is an attractive nuisance and that the probability that an illuminated individual will face the laser source is high. Since Nd-YAG radiation is not visible, an individual's protective blinking response to bright light furnishes no protection.

3.2.3.6 Probability of Illumination by Specular Reflection

The process of calculation of the probability of illumination of a point by a single pulse of reflected radiation is described in a past study. The mechanics of determining the angle δ_C are in this previous study, and in fact

$$\cos\delta_C = \bar{R}_L \cdot \bar{R}_{Lr} / (R_L)(R_{Lr}) \qquad 3.2.3.6.1$$

The variables in eqn. 3.2.3.6.1 are expressed using all of the transformations of table 3.1.

One may construct examples for which the contribution to the probability of illumination of a point comes entirely from specular reflection.

4.0 TEST PLAN SIMULATION

The mathematics developed in section 3, and three-dimensional plotting subroutines generated by a previous study were incorporated into program LPHP (Appendix A) to provide test cases and examples for this study. A flow diagram of the model is shown by Figure 4.0.1, p. 4-3.

The geometry of the test plans, and the laser characteristics of the test cases are described in the following paragraphs.

4.1 Test Case Descriptions

All of the test cases used a distribution of the radial miss angle (δ_ϵ) constructed from a past study as shown in Figure 3.2.1.2, p. 3-8. A summary of the values used to produce the distribution follows:

Laser beam pointing uncertainty	α_{max} = .002 radians*
Laser beam half-angle divergence	ϕ = .0005 radians*
Standard deviation of the distribution	σ = .3 mils*
Mean of the distribution	μ = .362 mils*
$(\mu/\sigma)^2$	$a = 1.45604$
σ^2/μ	$b = 2.4862 \times 10^{-4}$
Truncation constant for α_{max}	$K_m = 1.00272$

The geometry of the test cases is described by a rectangular cartesian coordinate system in which positive x is north, positive z is east, and positive y is normal to the xz plane in an upwards direction.

*LPHP input values

(Revised 12/15/80)

The plots present a visual representation of the probability that a single point (the intersection of an x and z grid line) will be illuminated during the test.

Flow Diagram of Model

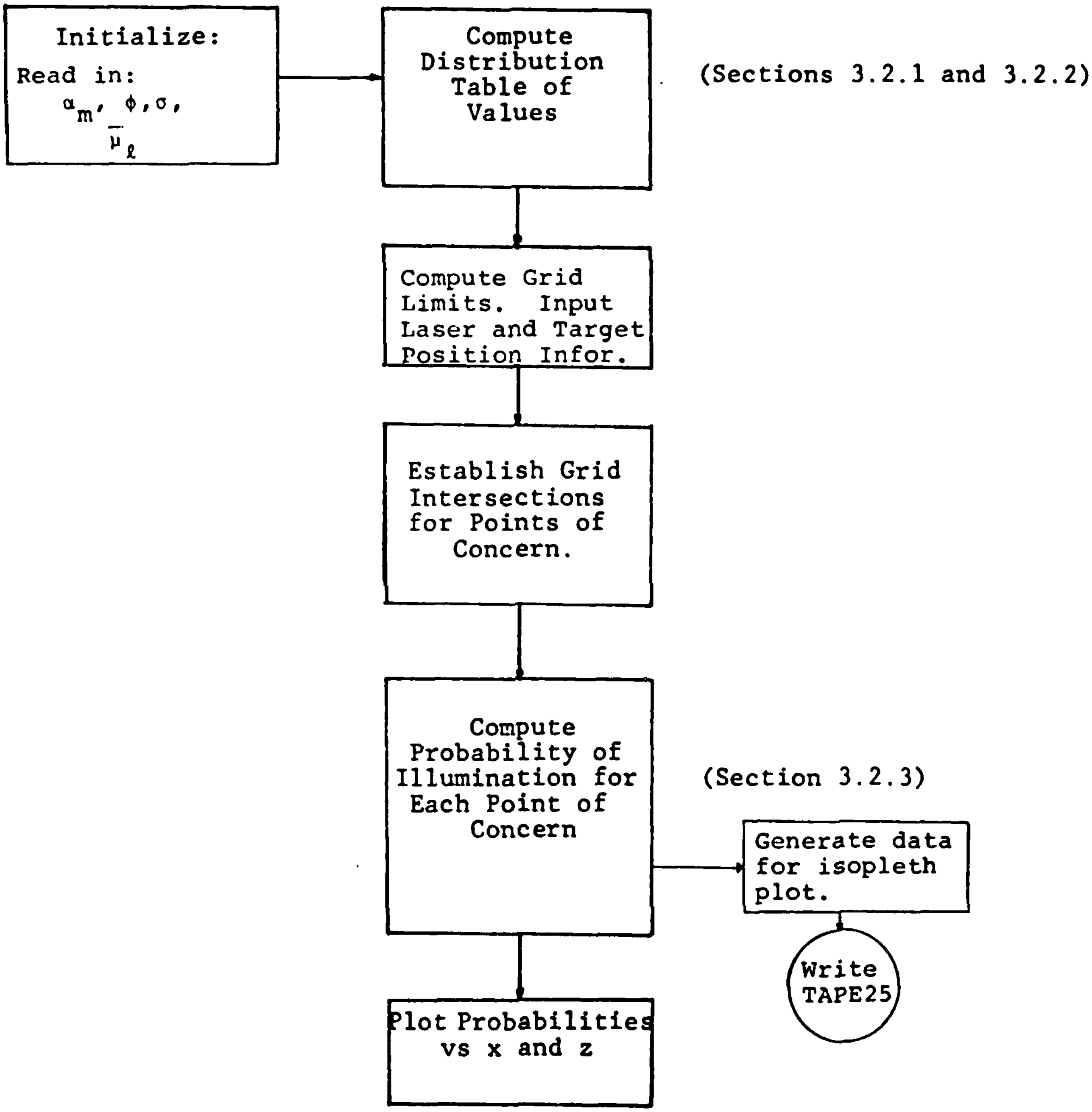


Figure 4.0.1

4.1.1 Case 1: Moving Laser, Stationary Target

In test case 1, the laser is moving at a rate of 900 ft/sec in an arc whose radius is 10000 feet. The time period is 10 seconds, and the pulse frequency of the laser is tenths of seconds. The positions of the laser are computed from the following equations:

$$x_L \text{ (ft)} = 25000. - 10000. \sin \frac{vt}{r}$$

$$y_L \text{ (ft)} = 400.$$

$$z_L \text{ (ft)} = 10000. \left(1 - \cos \frac{vt}{r}\right)$$

where $t = .1n$

$n = 0,1,2,\ldots,100$

The target, in this test case, is located at the origin of the coordinate system.

$$x_T \text{ (ft)} = 0.0$$

$$y_T \text{ (ft)} = 0.0$$

$$z_T \text{ (ft)} = 0.0$$

The relative positions of the laser and target are shown in Figure 4.1.1.1, while the probabilities of illumination of points surrounding the target are plotted in Figure 4.1.1.2, p. 4-6. Numerical values of the probabilities are listed in Figure 4.1.1.3, p. 4-7. A plot of the locus of points for which the probability of illumination is 10^{-2} (i.e., the 10^{-2} isopleth) is given in Figure 4.1.1.4, p. 4- 8. To construct the figure 4.1.1.4 isopleth, the granularity of the figure 4.1.1.3 array was refined to contain 1600 points.

Case 1

Moving Laser, Stationary Target
Relative Positions

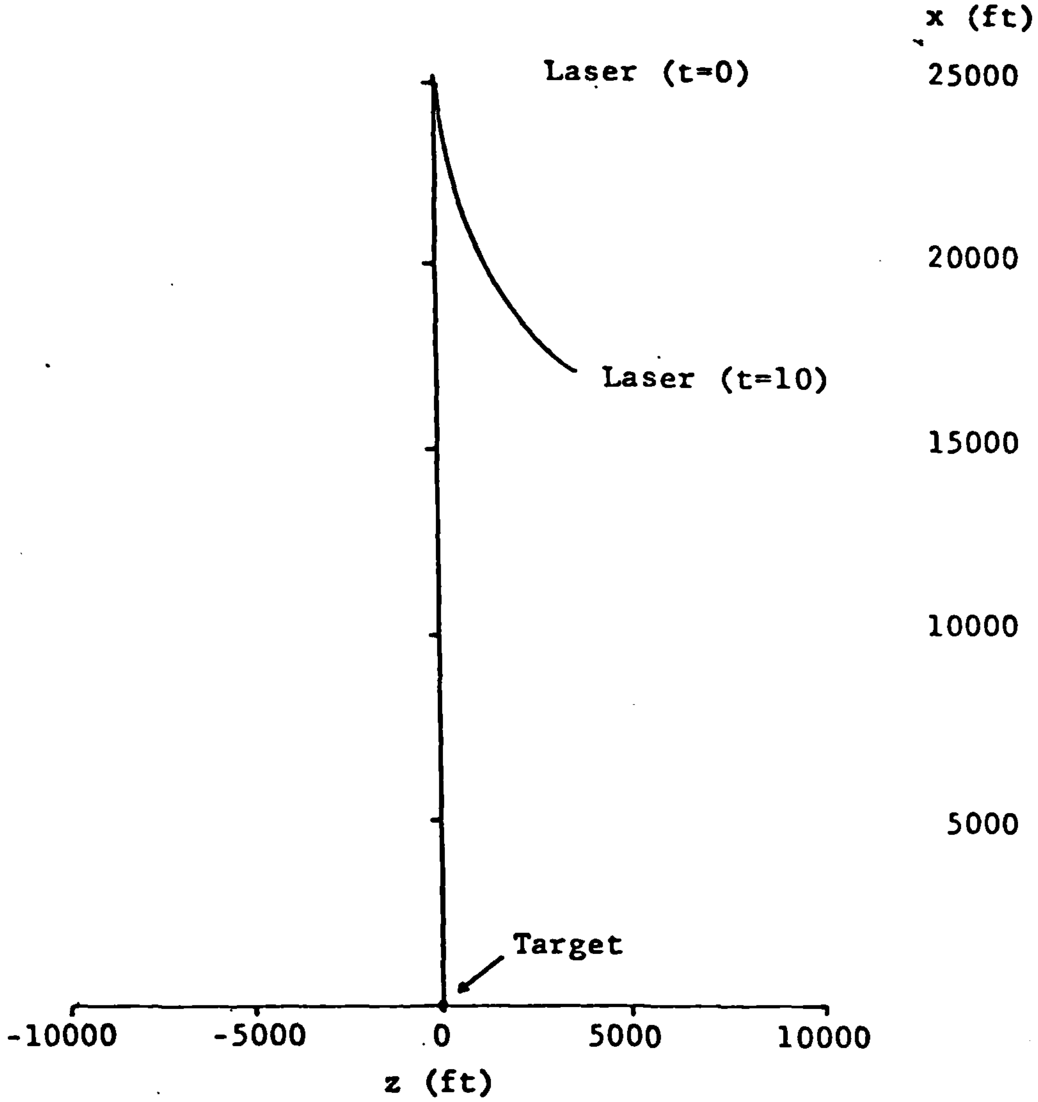


Figure 4.1.1.1

Case 1

Moving Laser, Stationary Target
Probability of Illumination

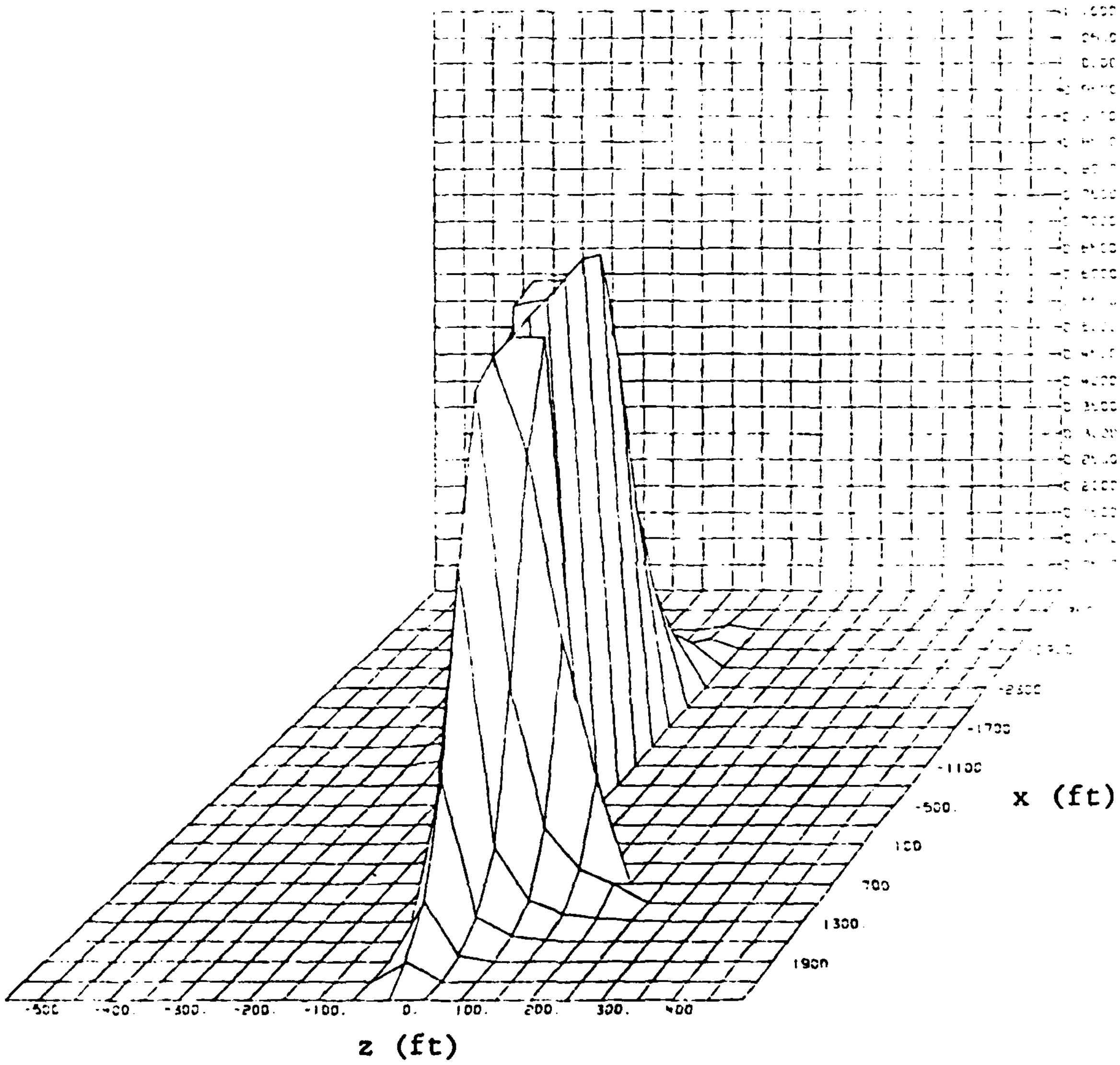


Figure 4.1.1.2

CASE 1

MOVING LASER, STATIONARY TARGET
PROBABILITY OF ILLUMINATION

z (ft)

x (ft)	-500.0	-450.0	-400.0	-350.0	-300.0	-250.0	-200.0	-150.0	-100.0	-50.0
2500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1900.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1300.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
700.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
100.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.9875E+00
-500.0	0.	0.	0.	0.	0.	0.	0.	0.	.8536E+00	.5940E+00
-800.0	0.	0.	0.	0.	0.	0.	.4015E-02	.2473E+00	.4243E+00	.8067E+00
-1100.0	0.	0.	0.	0.	0.	.1212E-01	.5510E-01	.9136E-01	.1772E+00	.4443E+00
-1400.0	0.	0.	0.	0.	.6434E-02	.1111E-01	.1807E-01	.3273E-01	.7148E-01	.2173E+00
-1700.0	0.	0.	0.	0.	.1550E-02	.3044E-02	.6034E-02	.1760E-01	.2943E-01	.9903E-01
-2000.0	0.	0.	0.	0.	0.	0.	.9555E-03	.4188E-02	.1213E-01	.4550E-01
-2300.0	0.	0.	0.	0.	0.	0.	0.	0.	.4254E-02	.1976E-01
-2600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.6858E-02
-2900.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

x (ft)	0.0	50.0	100.0	150.0	200.0	250.0	300.0	350.0	400.0	450.0
2500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2200.0	.3899E-01	0.	0.	0.	0.	0.	0.	0.	0.	0.
1900.0	.1135E+00	.1319E-01	.1015E-02	0.	0.	0.	0.	0.	0.	0.
1600.0	.3058E+00	.4603E-01	.1131E-01	.4152E-02	0.	0.	0.	0.	0.	0.
1300.0	.6746E+00	.1414E+00	.4171E-01	.1724E-01	.8067E-02	.4263E-02	0.	0.	0.	0.
1000.0	.9746E+00	.4160E+00	.1435E+00	.6533E-01	.3666E-01	0.	0.	0.	0.	0.
700.0	.1000E+01	.8160E+00	.4602E+00	.2007E+00	0.	0.	0.	0.	0.	0.
400.0	.1000E+01	.9995E+00	.2027E+00	0.	0.	0.	0.	0.	0.	0.
100.0	.1000E+01	.2793E-01	0.	0.	0.	0.	0.	0.	0.	0.
-200.0	.1000E+01	.1018E-02	0.	0.	0.	0.	0.	0.	0.	0.
-500.0	.1000E+01	.1009E-02	0.	0.	0.	0.	0.	0.	0.	0.
-800.0	.1000E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1100.0	.9706E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1400.0	.7185E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1700.0	.4195E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2000.0	.2154E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2300.0	.1026E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2600.0	.4902E-01	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2900.0	.2202E-01	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3200.0	.9286E-02	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3500.0	.1453E-02	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure 4.1.1.3

Case 1: 10^{-2} Isopleth

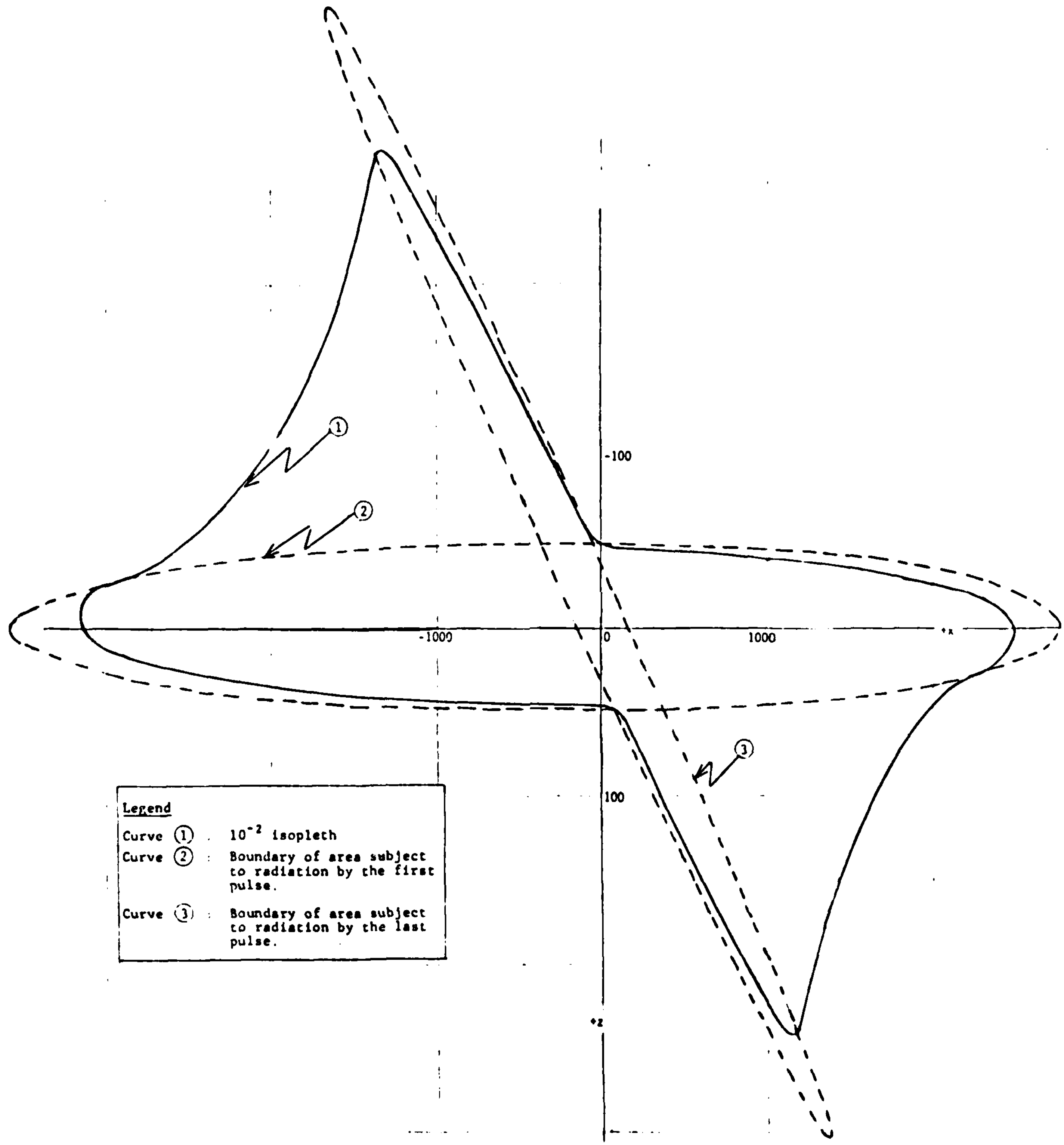


Figure 4.1.1.4

4.1.2 Case 2: Moving Laser, Moving Target

The laser positions for test case 2 are those described in test case 1. The target, in test case 2, is assumed to move in the xz plane along the z axis at a rate of 70 ft/sec, and does not deviate from the x axis:

$$x = 0.0$$

$$y = 0.0$$

$$z = 70t$$

where $t = .1n$

$$n = 0,1,\ldots,100$$

The relative positions of the laser and target, the plots of the probability of illumination data, and the numerical probability data, are shown in Figures 4.1.2.1, 4.1.2.2, and 4.1.2.3, pp. 4-10, 4-11, 4-12.

Case 2

Moving Laser, Moving Target
Relative Positions

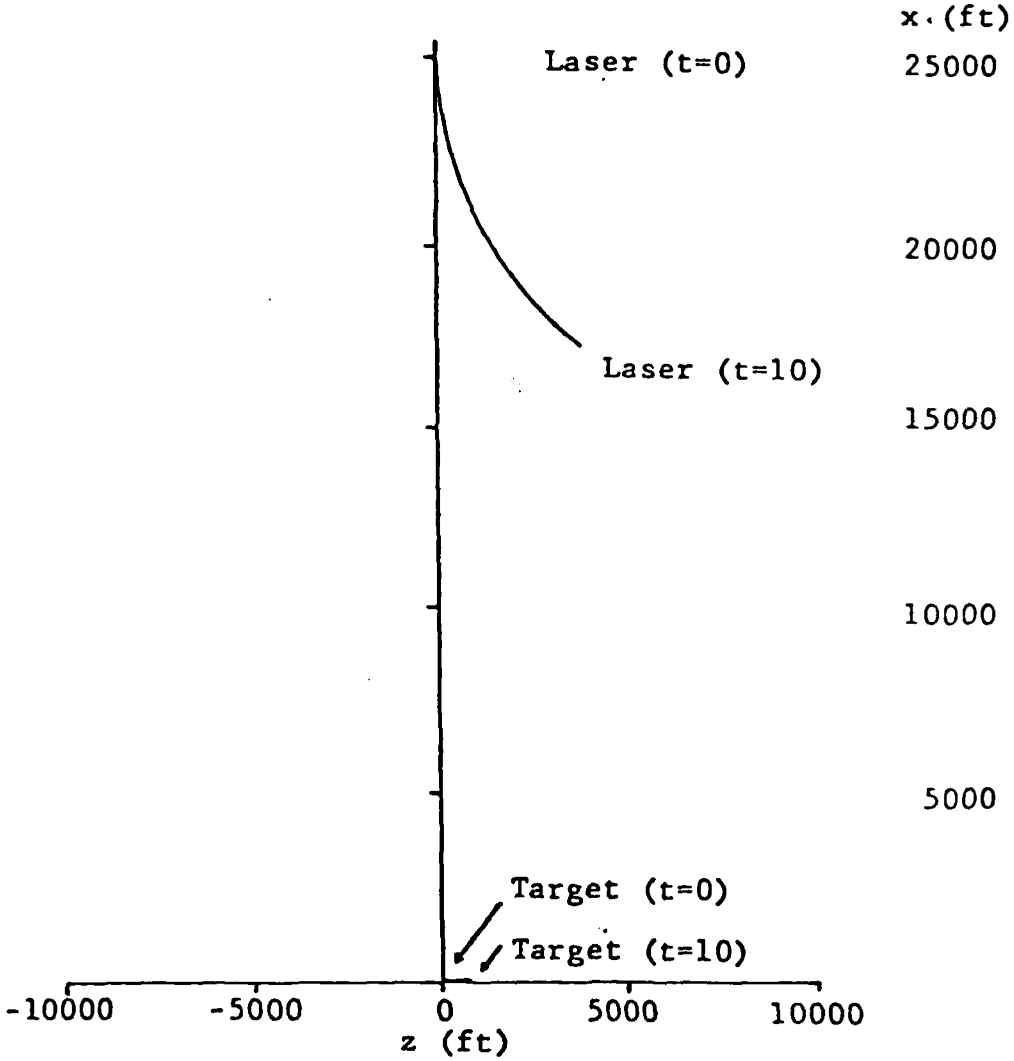


Figure 4.1.2.1

Case 2

Moving Laser, Moving Target
Probability of Illumination

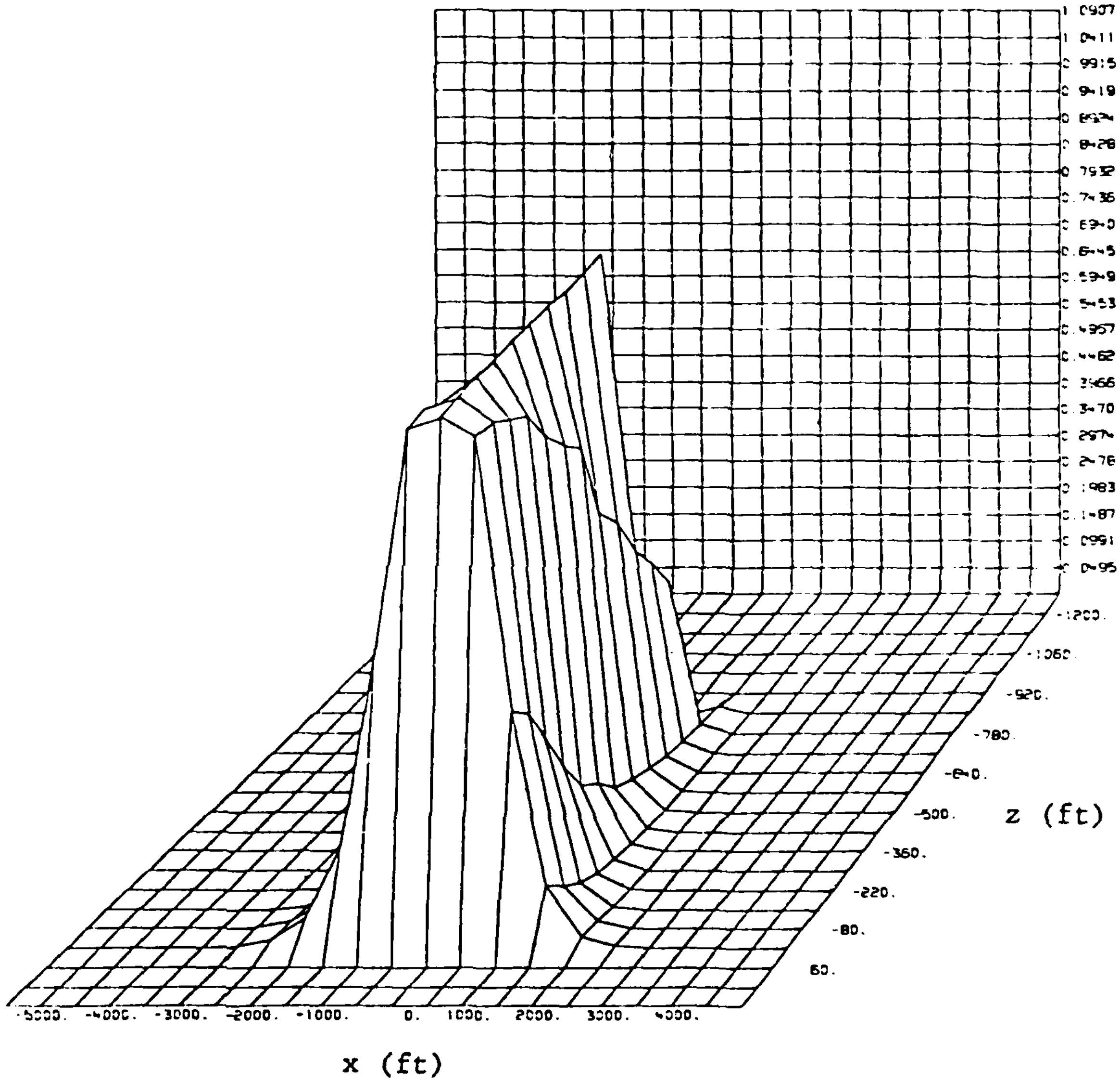


Figure 4.1.2.2

CASE 2

MOVING LASER, MOVING TARGET

z (ft) \ x (ft)	-5000.0	-4500.0	-4000.0	-3500.0	-3000.0	-2500.0	-2000.0	-1500.0	-1000.0	-500.0
200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
130.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
60.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-10.0	0.	0.	0.	.1013E-02	.5829E-02	.1935E-01	.5941E-01	.1981E+00	.5412E+00	.9679E+00
-80.0	0.	0.	0.	0.	.4090E-02	.1594E-01	.5461E-01	.1723E+00	.5419E+00	.9664E+00
-150.0	0.	0.	0.	0.	0.	.1019E-01	.3891E-01	.1392E+00	.4265E+00	.9471E+00
-220.0	0.	0.	0.	0.	0.	.4823E-02	.2324E-01	.5691E-01	.3535E+00	.9344E+00
-290.0	0.	0.	0.	0.	0.	0.	.1426E-01	.6751E-01	.2335E+00	.9146E+00
-360.0	0.	0.	0.	0.	0.	0.	0.	.4306E-01	.2249E+00	.8613E+00
-430.0	0.	0.	0.	0.	0.	0.	0.	.1797E-01	.1712E+00	.8224E+00
-500.0	0.	0.	0.	0.	0.	0.	0.	0.	.1155E+00	.7091E+00
-570.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.5919E+00
-640.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1456E-02
-710.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-780.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-850.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-920.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-990.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1060.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1130.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1270.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

z (ft) \ x (ft)	0.0	500.0	1000.0	1500.0	2000.0	2500.0	3000.0	3500.0	4000.0	4500.0
200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
130.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
60.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-10.0	.5159E+00	.9531E+00	.6648E+00	.1194E+00	.2298E-01	.4483E-02	0.	0.	0.	0.
-80.0	.5912E+00	.9451E+00	.4019E+00	.8153E-01	.1537E-01	.1217E-02	0.	0.	0.	0.
-150.0	.9916E+00	.9137E+00	.3243E+00	.5474E-01	.8764E-02	0.	0.	0.	0.	0.
-220.0	.9873E+00	.8232E+00	.2331E+00	.3305E-01	.3480E-02	0.	0.	0.	0.	0.
-290.0	.9556E+00	.8276E+00	.1622E+00	.2320E-01	.2022E-02	0.	0.	0.	0.	0.
-360.0	.9810E+00	.7542E+00	.1278E+00	.1426E-01	.5137E-03	0.	0.	0.	0.	0.
-430.0	.9812E+00	.7129E+00	.8531E-01	.8631E-02	0.	0.	0.	0.	0.	0.
-500.0	.9714E+00	.5550E+00	.6278E-01	.5123E-02	0.	0.	0.	0.	0.	0.
-570.0	.9723E+00	.4989E+00	.6626E-01	.3152E-02	0.	0.	0.	0.	0.	0.
-640.0	.9662E+00	.4097E+00	.2228E-01	.1897E-02	0.	0.	0.	0.	0.	0.
-710.0	.3144E+00	.3530E+00	.2339E-01	.1164E-02	0.	0.	0.	0.	0.	0.
-780.0	0.	.2822E+00	.1844E-01	.5180E-03	0.	0.	0.	0.	0.	0.
-850.0	0.	0.	.1323E-01	0.	0.	0.	0.	0.	0.	0.
-920.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-990.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1060.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1130.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1270.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure 4.1.2.3

4.1.3 Case 3. Moving Laser, Stationary Target

The laser in this test case is moving on the x axis towards the origin of the coordinate system at a rate of one foot per second, originating at a point 25000 feet from the origin. The height of the laser is 400 feet above the xz plane.

$$x \text{ (ft.)} = 25000.0 - t$$

$$y \text{ (ft.)} = 400.0$$

$$z \text{ (ft.)} = 0.0$$

where

$$t = .1n$$

$$n = 0,1,\ldots,100$$

The target is located at the origin.

The laser-target configuration is shown in Figure 4.1.3.1; the plots of the probability data and the the numerical values are presented in Figures 4.1.3.2 and 4.1.3.3, pgs. 4-15 and 4-16.

Case 3

Moving Laser, Stationary Target
Relative Positions

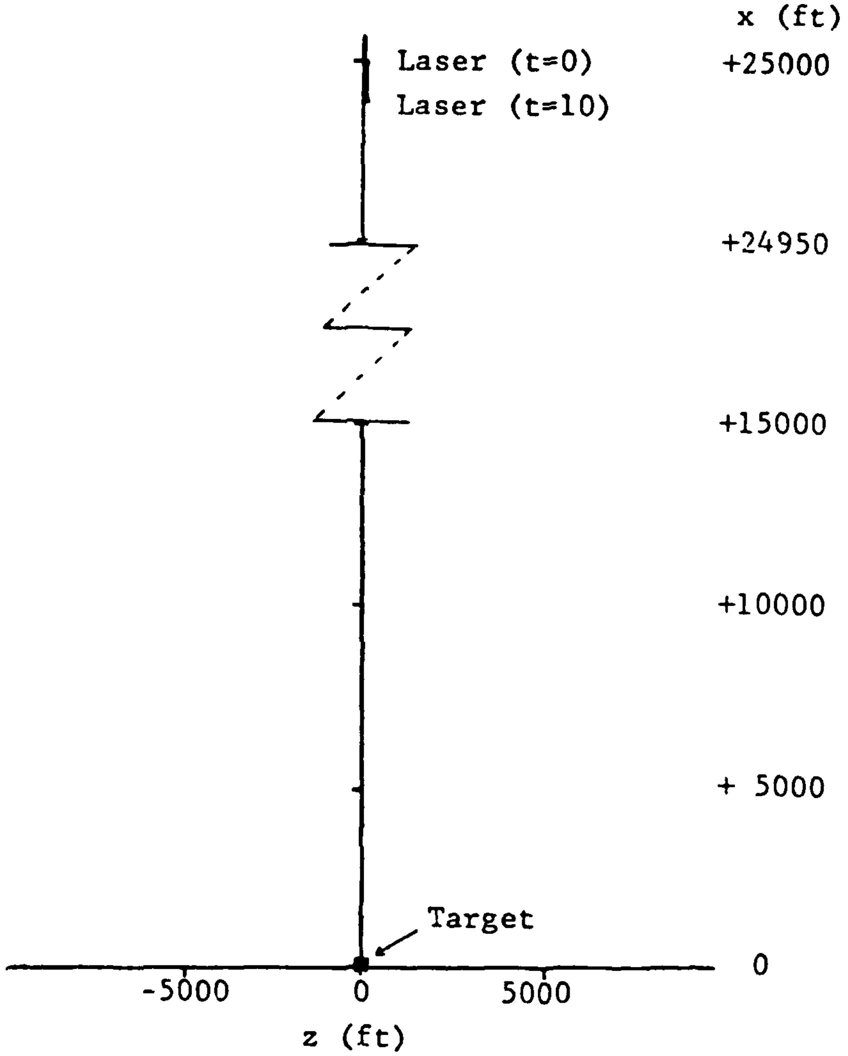


Figure 4.1.3.1

Case 3

Moving Laser, Stationary Target
Probability of Illumination

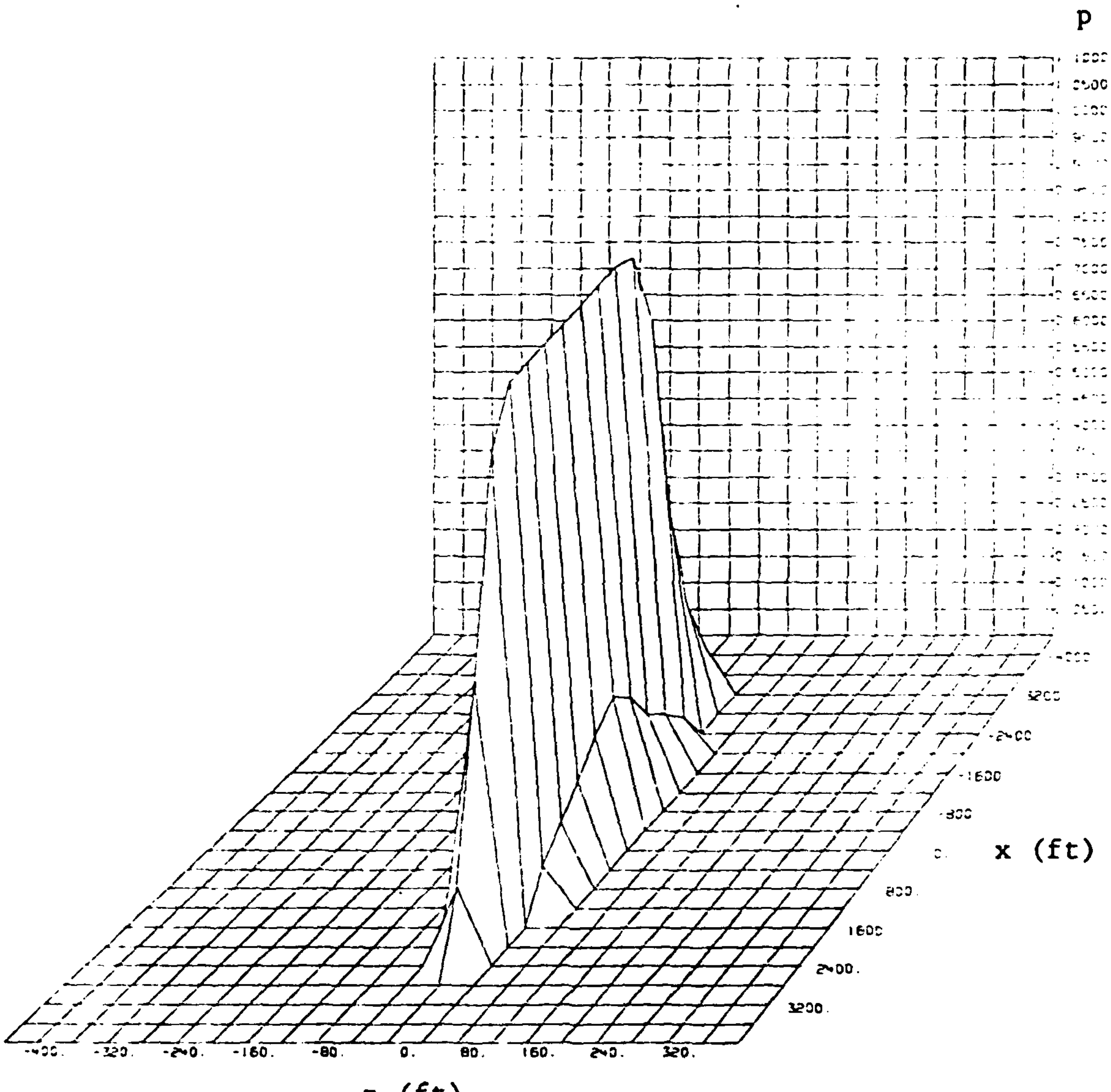


Figure 4.1.3.2

CASE 3

MOVING LASER, STATIONARY TARGET
PROBABILITY OF ILLUMINATION

x (ft) \ z (ft)	-400.0	-360.0	-320.0	-280.0	-240.0	-200.0	-160.0	-120.0	-80.0	-40.0
4000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.8073E-01
800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1282E+00
400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1714E+00
0.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2175E+00
-400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2563E+00
-800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2152E+00
-1200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1496E+00
-1600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1127E+00
-2000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.6668E-01
-2400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-4000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-4400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

x (ft) \ z (ft)	0.0	40.0	80.0	120.0	160.0	200.0	240.0	280.0	320.0	360.0
4000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2800.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2400.0	.1526E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.0	.5877E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
1600.0	.9054E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
1200.0	.9998E+00	.8073E-01	0.	0.	0.	0.	0.	0.	0.	0.
800.0	.1000E+01	.1282E+00	0.	0.	0.	0.	0.	0.	0.	0.
400.0	.1000E+01	.1714E+00	0.	0.	0.	0.	0.	0.	0.	0.
0.0	.1000E+01	.2175E+00	0.	0.	0.	0.	0.	0.	0.	0.
-400.0	.1000E+01	.2563E+00	0.	0.	0.	0.	0.	0.	0.	0.
-800.0	.1000E+01	.2152E+00	0.	0.	0.	0.	0.	0.	0.	0.
-1200.0	.1000E+01	.1496E+00	0.	0.	0.	0.	0.	0.	0.	0.
-1600.0	.9605E+00	.1127E+00	0.	0.	0.	0.	0.	0.	0.	0.
-2000.0	.3164E+00	.6666E-01	0.	0.	0.	0.	0.	0.	0.	0.
-2400.0	.4110E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2800.0	.2040E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3200.0	.9245E-01	0.	0.	0.	0.	0.	0.	0.	0.	0.
-3600.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-4000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-4400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure 4.1.3.3

4.1.4 Case 4: Single Time Point

It is desirable to know, for a single pulse of the laser, the probability of illumination of the points surrounding the target. Test case 4 presents the probability for a single pulse with the target located at the origin, and the laser located at:

$x = 20000.$ ft.

$y = 400.$ ft.

$z = 0.0$ ft.

The plot of the probability of illumination of the surrounding points, and the numerical data of these probabilities are shown in Figures 4.1.4.1 and 4.1.4.2, p. 4-18 and 4-19.

Case 4

Single Point Laser Pulse
Probability of Illumination

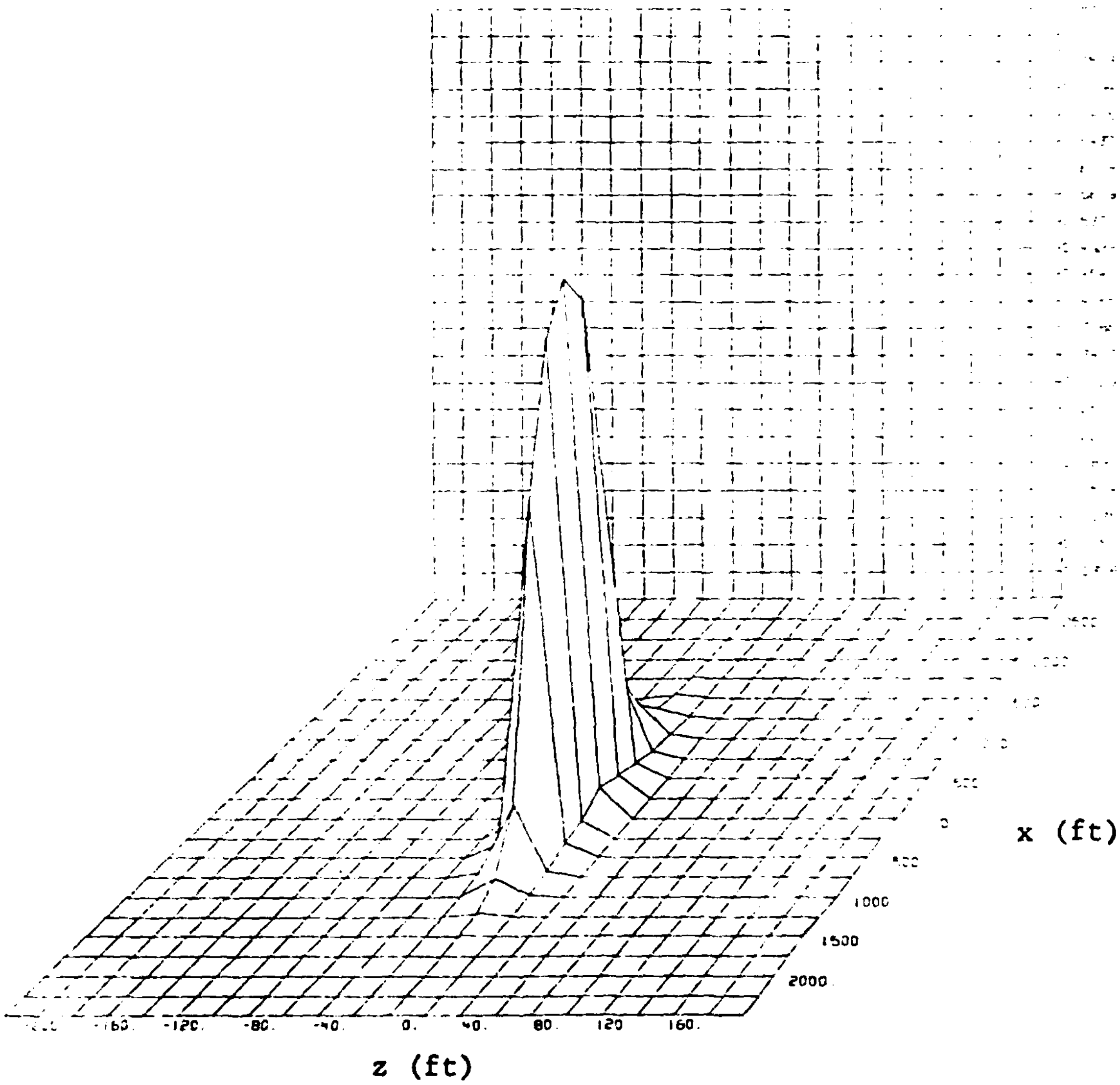


Figure 4.1.4.1

CASE 4

SINGLE POINT LASER PULSE
PROBABILITY OF ILLUMINATION

z (ft)

x (ft)	-200.0	-180.0	-160.0	-140.0	-120.0	-100.0	-80.0	-60.0	-40.0	-20.0
2250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1750.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.5977E-
1250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1684E-
1000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.3769E-
750.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.9513E-
500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2016E-
250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2655E-
0.0	0.	0.	0.	0.	0.	0.	0.	0.	.5234E-03	.4415E-
-250.0	0.	0.	0.	0.	0.	0.	0.	0.	.5067E-03	.3378E-
-500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2275E-
-750.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.1290E-
-1000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.8204E-
-1250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.4033E-
-1500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.2074E-
-1750.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.7980E-
-2000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

x (ft)	0.0	20.0	40.0	60.0	80.0	100.0	120.0	140.0	160.0	180.0
2250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1750.0	.7325E-03	0.	0.	0.	0.	0.	0.	0.	0.	0.
1500.0	.2336E-02	.5977E-03	0.	0.	0.	0.	0.	0.	0.	0.
1250.0	.7790E-02	.1684E-02	0.	0.	0.	0.	0.	0.	0.	0.
1000.0	.2749E-01	.3769E-02	0.	0.	0.	0.	0.	0.	0.	0.
750.0	.1652E+00	.9513E-02	0.	0.	0.	0.	0.	0.	0.	0.
500.0	.4968E+00	.2016E-01	0.	0.	0.	0.	0.	0.	0.	0.
250.0	.7033E+00	.2655E-01	0.	0.	0.	0.	0.	0.	0.	0.
0.0	.7573E+00	.4415E-01	.5234E-03	0.	0.	0.	0.	0.	0.	0.
-250.0	.6993E+00	.3378E-01	.5067E-03	0.	0.	0.	0.	0.	0.	0.
-500.0	.4401E+00	.2275E-01	0.	0.	0.	0.	0.	0.	0.	0.
-750.0	.1194E+00	.1290E-01	0.	0.	0.	0.	0.	0.	0.	0.
-1000.0	.5170E-01	.8204E-02	0.	0.	0.	0.	0.	0.	0.	0.
-1250.0	.1617E-01	.4033E-02	0.	0.	0.	0.	0.	0.	0.	0.
-1500.0	.7076E-02	.2074E-02	0.	0.	0.	0.	0.	0.	0.	0.
-1750.0	.2230E-02	.7980E-03	0.	0.	0.	0.	0.	0.	0.	0.
-2000.0	.9659E-03	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2250.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2500.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure 4.1.4.2

APPENDIX A

A.1 Laser Probability of Hazard Program, LPHP

A.1.1 Input and Processing

Program LPHP is designed to operate upon data and data base constants contained in card decks, or card deck image disk files. These decks or files may be created by employing the EDITOR mode of the CDC 6600/Cyber 176 computer system; by punching cards on an 029 IBM keypunch, or by executing the Laser Interactive Data base Input (LIDI) program which was written to create disk file input for LPHP.

Execution of program LPHP may be initiated from a remote terminal in either the "batch" mode, or the intercom mode. If card decks are employed for input, the program may be executed in the "batch" mode only.

Batch mode processing requires the addition of a job control stream of instructions to the CDC 6600/Cyber 176 computers immediately prior to the data base input. There are four basic rules concerning the job stream deck:

1. The first card must be a standard Job card.
2. All permanent files that will be used in the execution, including the LPHP and LISP (if desired) binary files, must be defined in the job stream.
3. All lines in the stream must terminate with a period or right parenthesis.
4. The job stream file must be terminated by an *EOR (7,8,9 punch in column 1).

Data base constants may be entered in one of two ways when operating the "batch" mode. The user has the option of placing the data base file in a permanent file, and "attaching" it in the job stream file; or, the data base disk file (deck) may follow the *EOR (7,8,9) line of the job stream file. The last lines (cards) of any "batch" job must be an *EOR (7,8,9) followed by an *EOF (6,7,8,9) line.

Jobs are executed in the "batch" mode from a remote terminal by entering the command: BATCH,JFN,INPUT where JFN is the local file name of the job stream.

Execution of jobs in the intercom mode requires that all inputs utilized by the job reside in local files at execution time. Initiation of execution is accomplished by enterinc the command: LPHPN,DBC, where N is the version number of LPHP and DBC is the disk file of data base input.

If the target and/or laser position data are to be input from disk files, these files must be named TAPE13 and TAPE11 when they are used (i.e., in the job stream if batch mode operation; in local files if intercom mode). They may exist under different permanent file names, however, so that multiple flight paths may be retained.

A.1.2 Output

The output from program LPHP is the probability of hazardous radiation incurred by each intersection of 20 abscissa and 20 ordinate grid lines in the ground plane during a period of laser operation. The probability values are presented in a

histogram plot and in tabular form.

Probability data written to TAPE25 for subsequent plotting by program LISP to obtain isopleths of hazardous probability levels are computed from a 43 by 43 grid.

A.1.3 Examples of Methods of Execution

The following file names will be used in the examples:

File Name	Description
LPHPN	Binary object file of the program
DBC	Data base input (stored in ID XX)
JCC	Job control cards
TAPE11	Disk file containing laser position data (ID XX)
TAPE13	Disk file containing target position data (ID XX)
LISPN	Binary file of isopleth plot program
TAPE25	LPHP output for LISP input

Note: The suffix N attached to the binary files represents a version number for compliance with the Software Control System developed under Study Task Order SESR 80-3 (12 August 1980). The proper version number may be obtained by an AUDIT command of ID=XY.

The password (PW=-----) attached to the binary files may be obtained from the Range Safety Software Monitor.

Example 1:

Card deck input, laser position on disk.

Job card

```
ATTACH,LPHPN,ID=XY,PW=-----.
ATTACH,TAPE11,ID=XX.
LPHPN.
7/8/9 (multipunch col. 1)
      Data base deck here
7/8/9 (multipunch col. 1)
6/7/8/9 (multipunch col.1)
```

Output results and plots automatically generated.

Example 2:

Batch mode file JCC, target position on disk.

```
Job card
ATTACH,LPHPN,ID=XY,PW=-----.
ATTACH,DBC,ID=XX.
ATTACH,TAPE13,ID=XX.
LPHPN,DBC.
```

To execute JCC from the remote terminal, move JCC into a local file and enter the command: BATCH,JCC,INPUT.

Example 3:

Intercom execution from disk file (TAPE5) created by program LIDI. Laser and target position data reside in ID=XX under file names LASPOS and TARPOS.

Step 1: ETL,500
Step 2: ATTACH,TAPE11,LASPOS,ID=XX
Step 3: ATTACH,TAPE13,TARPOS,ID=XX
Step 4: ATTACH,LIDIN,ID=XY,PW=-----.
Step 5: CONNECT,INPUTOUTPUT
Step 6: LIDIN
Step 7: DISCONT,INPUT,OUTPUT
Step 8: LPHPN
Step 9: PAGE,OUTPUT to examine tabular results
Step 10: DISPOSE,FILMPL,FL=CU1 to obtain histogram plots
Step 11: DISPOSE,OUTPUT,PR=CU1 to obtain tabular results

A.1.4 Processing Program LISP

If isopleth plots are desired, program LISP may be executed in either the batch or intercom mode.

In examples 1 and 2 of Section A.1.3, execution of program LISP is accomplished by adding the statement

```
ATTACH,LISPN,ID=XY,PW=-----.
LISPN.
```

immediately after the LPHPN execution card.

(Revised 12/15/80)

Intercom execution of program LISP requires the following steps to be added to those in Example 3 of Section A.1.3:

Step 12: ATTACH,LISPN,ID=XY,PW=-----.
Step 13: LISPN
Step 14: DISPOSE,FILMPL,FL=CU1

Isopleth plots of the data generated by program LPHP (on TAPE25) at the levels specified in the data base constants for LPHP, are produced from these instructions. One plot, containing up to two isopleth levels, is produced for each SEED value entered into LPHP via the data base constants.

A sample isopleth plot generated by LISP, utilizing the data produced by LPHP for Case 1, Section 4.1.1, follows.

A.1.5 Batch Mode Data Base Inputs

A standard field format of 12 columns per input variable has been established for this program. The beginning columns for each field are, therefore:

2, 14, 26, 38, 50, 62

Each input value may be a floating point or exponential value (integers not allowed). Floating point numbers may be located anywhere in the field, exponential values must be right-justified in the field.

The first line of the deck is an alphameric identifier for the run, and contains user information in columns 2 through 72.

Termination of the program occurs by entry of the word END in columns 3 - 5.

Isopleth Plot of Case 1 Data from Program LISP

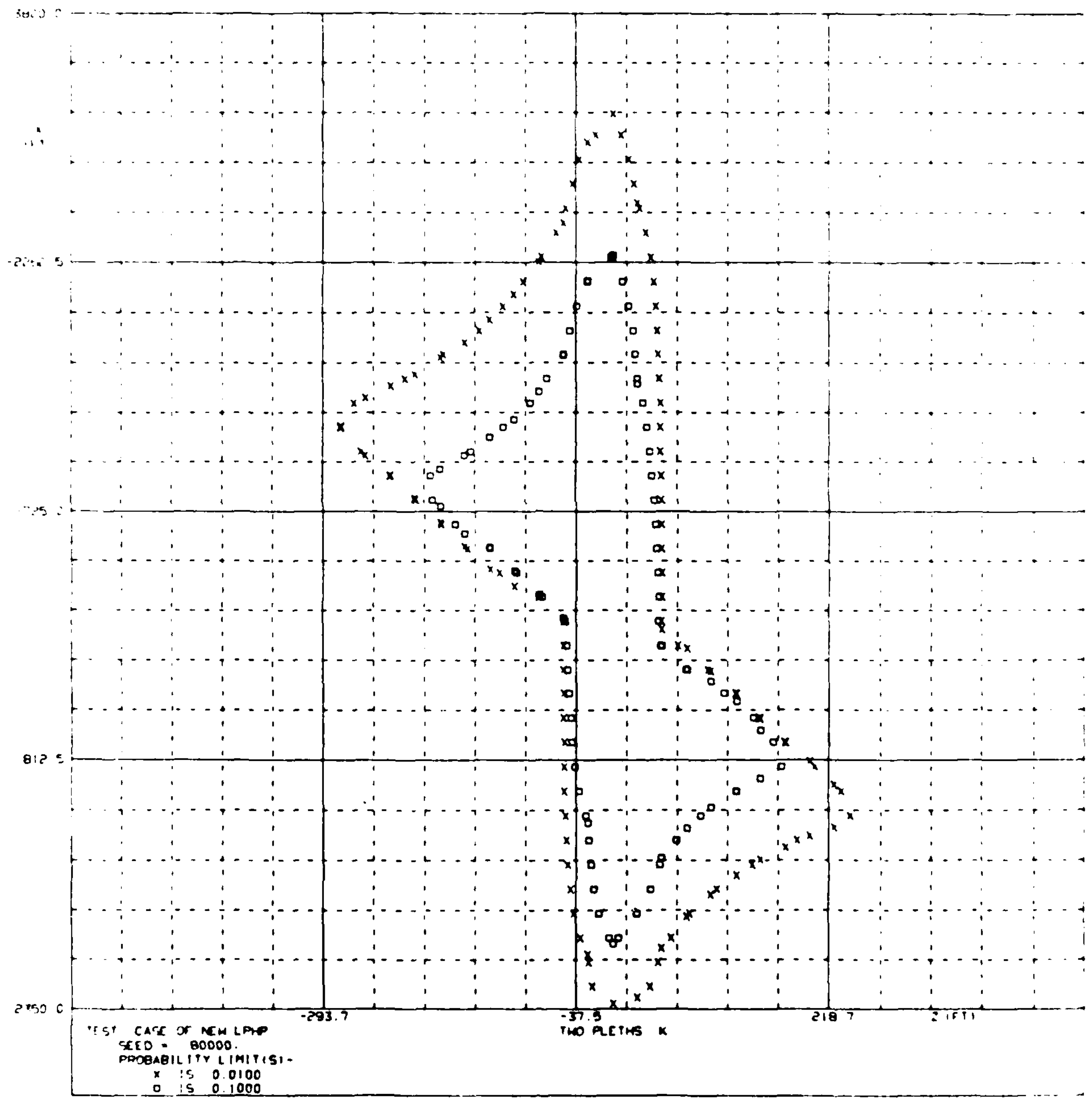


Figure A.1.4.1

Group 1: Option Choices

Card	Field	Description
1	1	Problem type: 2. = Stationary target, moving laser. 5. = Moving target, moving laser. 8. = Stationary target, stationary laser. Note: Cases involving reflective surfaces are not permitted in LPHP.

Group 2: Data Base for All Options

Card	Field	Description
1	1	Number of SEED values to follow (Max. = 3, one plot per SEED)
2	1	First SEED value (feet)
2a	1	Second SEED value (feet)
2b	1	Third SEED value (feet)
3	1	Mean of the gamma function (μ)
	2	Standard deviation of the gamma function (σ)
	3	Beam divergence of the laser (mils, full angle)
	4	Isopleth plot value no. 1 (ex 1.E-02)
	5	Isopleth plot value no. 2
4	1	Maximum excursionangle (mils) (same as laser beam cone pointing uncertainty)
	2	Target input system 1.=Geodetic, 0.=Rectangular
	3	Laser input system. 1.=Geodetic,0.=Rectangular
5	1	Geodetic latitude of the coordinate system to which rectangular data are referenced. (Degrees, north positive)
	2	Geodetic longitude of the coordinate system to which rectangular data are referenced. (Degrees, east positive)

Group 3: Data Base Input for Problem Type 2.

Card	Field	Description
1	1	Time (may be first time of laser position).
	2	Target Latitude (deg., north pos.) or target X (north; feet).
	3	Target Longitude (deg., east pos.) or target Z (east; feet).
	4	Target altitude (feet) or Y (up; feet).

Card	Field	Description
3	1	1. = Laser position data follow this card. 0. = Laser position data reside on disk (Tape 11)*
4-n		Insert these cards only if card 3, field 1 = 1.
	1	Time (may be seconds, or any sequential number). Laser Latitude (deg., north pos.) or target X (north; feet).
	3	Laser Longitude (deg., east pos.) or target Z (east; feet).
	4	Laser Altitude (feet) or target Y (up; feet).
n+1	1	9999999. Last card of this set
5	1	1 END (title card)

Group 4: Data Base Input for Problem Type 5.

Card	Field	Description
1	1	1. = Moving target position data follow this card. 0. = Moving target position data reside on disk (TAPE13)*
	2	1. = Moving laser position data follow this card. 0. = Moving laser position data reside on disk (TAPE11)*
2-n		Enter these cards only if card 1, field 1 = 1.
	1	Time (may be seconds, or any sequential number, but must agree with laser position time).
	2	Target Latitude (deg., north pos.) or X (north, feet).
	3	Target Longitude (deg., east pos.) or Z (east, feet).
	4	Target altitude (feet) or Y (up; feet).
n+1	1	9999999. = Last card of this set.
n+2-m		Enter these cards only if card 1, field 2 = 1.
	1	Time (may be seconds, or any sequential number, but must agree with target position time).
	2	Laser Latitude (deg., north pos.) or X (north, feet).
	3	Laser Longitude (deg., east pos.) or Z (east, feet).
	4	Laser altitude (feet) or Y (up; feet).
m+1	1	9999999. = Last card of this set.
5	1	1 END (title card)

Group 5: Data Base Input for Problem Type 8.

Card	Field	Description
1	1	Target Latitude (deg., north pos.) or X (north,feet)
	2	Target Longitude (deg., east pos.) or Z (east,feet).
	3	Target altitude (feet) or Y (up,feet).
2	1	Laser Latitude (deg., north pos.) or X (north,feet).
	2	Laser Longitude (deg., east pos.) or Z (east,feet).
	3	Laser altitude (feet) or Y (up,feet).
3	1	1 END (title card).

(Revised 12/15/80)

A.2 Sample Outputs: LPHP and LISP

The printed probability data, the probability histograms, and the isopleth plots presented in this section were computed from the data base created by program LIDI, and a target/laser scenario as described by Case 1 in Section 4.1.1 of this report. Creation of ten seconds of moving laser position data was accomplished by a FORTRAN V computer program which employed the equations shown on Page 4-4 of this report. These data were entered into LPHP as TAPE11.

The printed output is shown for only one of the SEED values entered in the LPHP data base input. Since both SEED values were large enough for all points to be valid, the probability data were identical. This accounts for the similarity between the two histograms and isopleth plots.

Printed Output

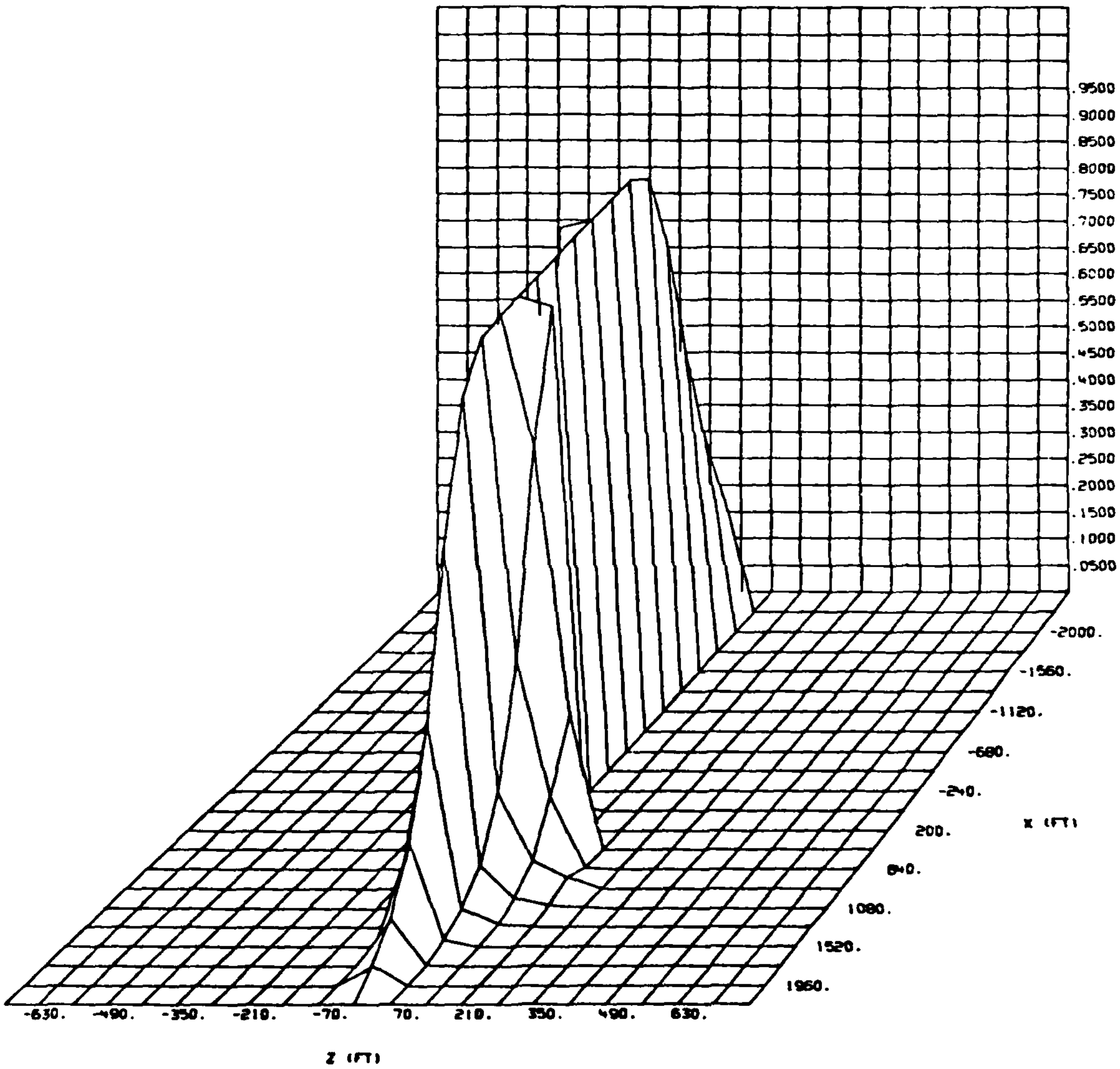
SAMPLE TEST CASE, TYPE 2
SUM OF PROBABILITY POINTS= .2070350E+02
EAST WEST

		-630.0	-560.0	-490.0	-420.0	-350.0	-280.0	-210.0	-140.0	-70.0	0.0
2400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
1960.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
1740.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
1520.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
1300.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
1080.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
860.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
640.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
420.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
200.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
-20.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]
-240.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]	[illegible]
-460.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	.5325E+[illegible]	[illegible]
-680.0	0.	0.	0.	0.	0.	0.	0.	0.	[illegible]	.7545E+[illegible]	[illegible]
-900.0	0.	0.	0.	0.	0.	0.	0.	[illegible]	[illegible]E+00	.48 4E+0[illegible]	[illegible]
-1120.0	0.	0.	0.	0.	0.	0.	0.	.45.7E-0[illegible]	[illegible]E+00	[illegible]	[illegible]
-1340.0	0.	0.	0.	0.	0.	0.	[illegible]E-0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
-1560.0	0.	0.	0.	0.	0.	.54[illegible]E-02	.4253E-02	.5890E-02	[illegible]	.8703E-[illegible]	[illegible]
-1780.0	0.	0.	0.	0.	0.	0.	.5350E-02	.380 E-0[illegible]	[illegible]	.455[illegible]	[illegible]
-2000.0	0.	0.	0.	0.	0.	0.	0.	.5074E-0[illegible]	.5377E-02	.2555E-[illegible]	[illegible]
-2220.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

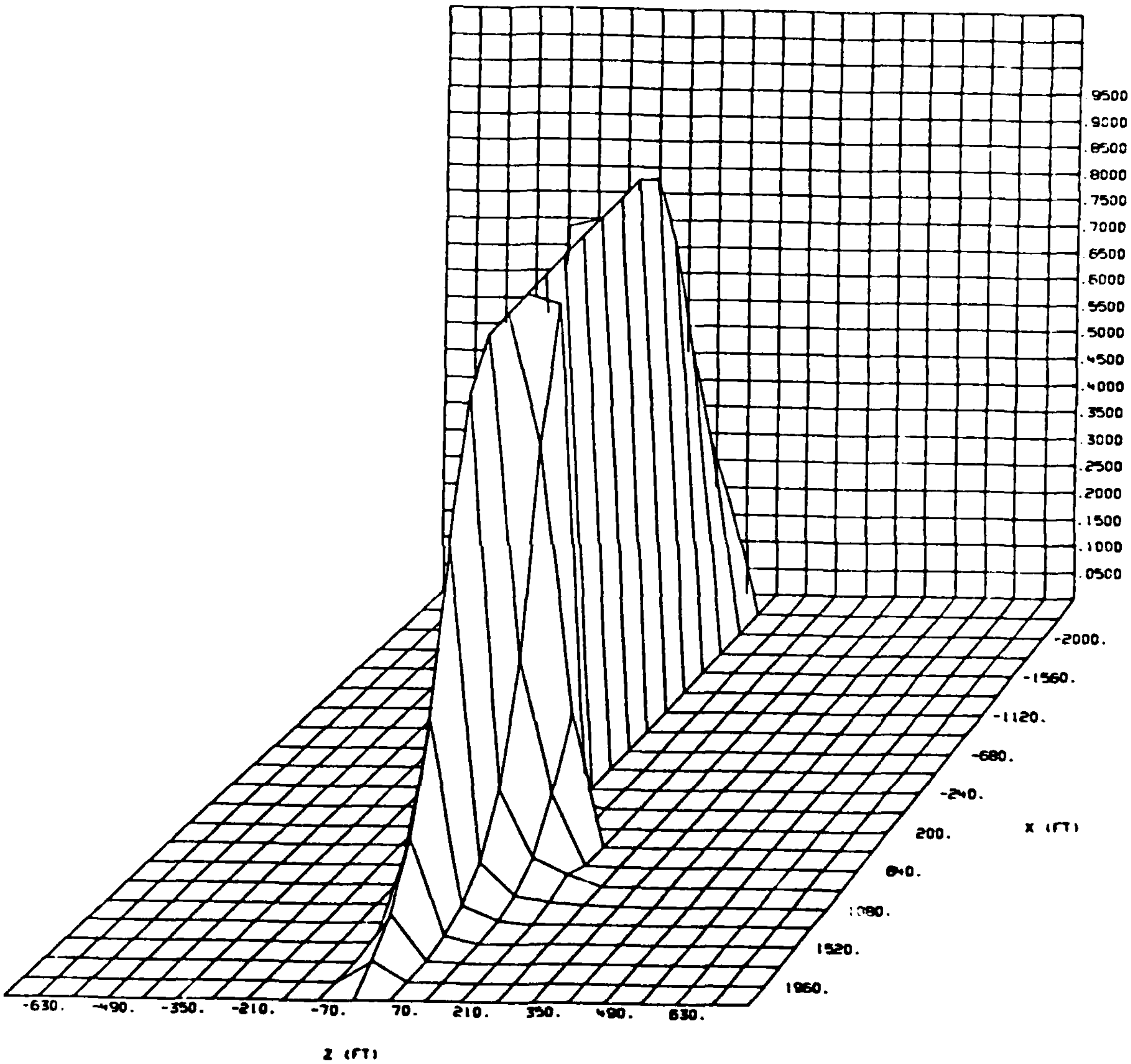
Printed Output (continued)

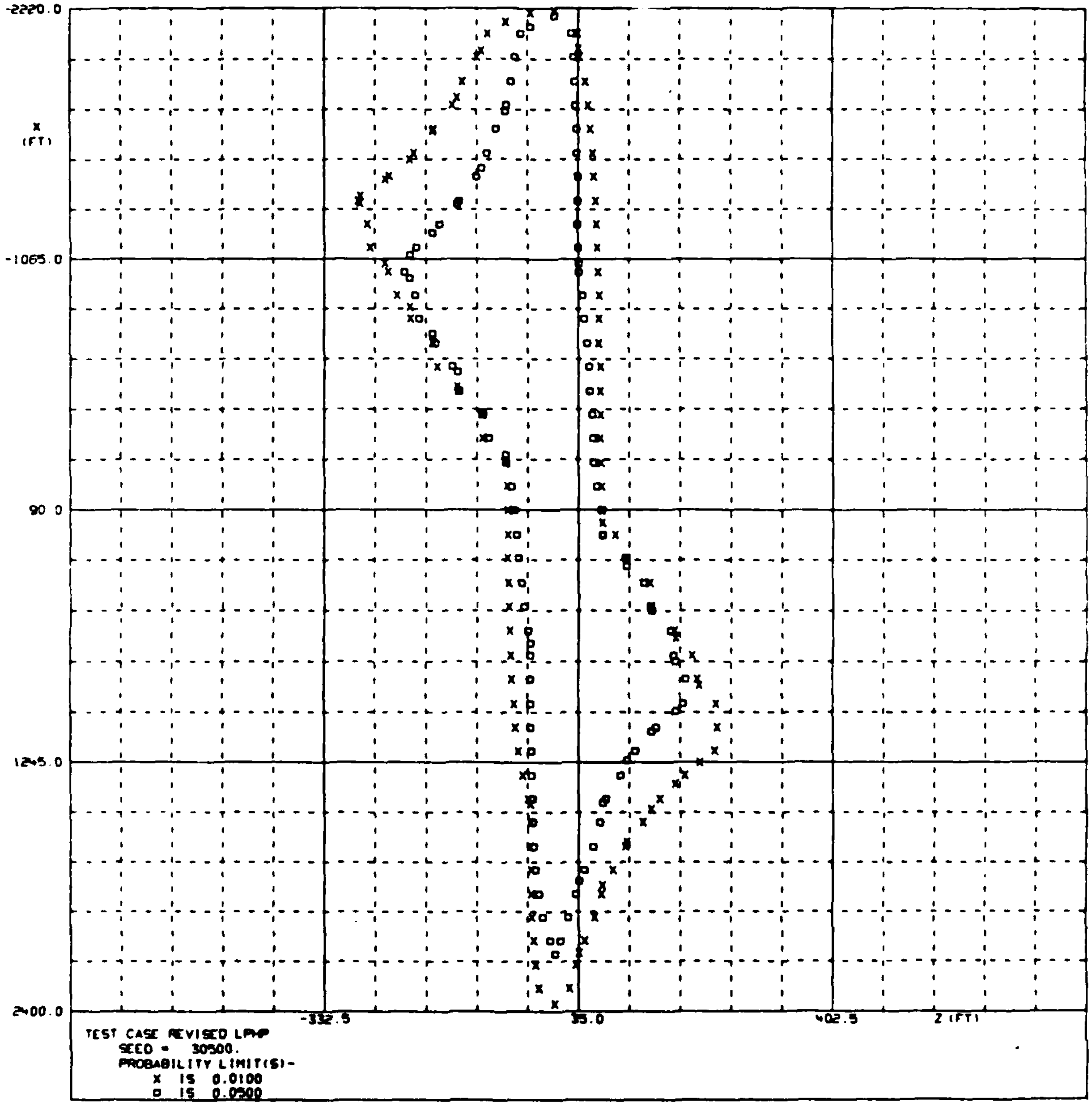
	70.0	140.0	210.0	280.0	350.0	420.0	490.0	560.0	630.0	[illegible]
2400.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2180.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1960.0	.4195E-07	0.	0.	0.	0.	0.	0.	0.	0.	0.
1740.0	.1374E-0[illegible]	.2556E-03	0.	0.	0.	0.	0.	0.	0.	0.
1520.0	.3551E-0[illegible]	.7546E-02	.1658E-07	0.	0.	0.	0.	0.	0.	0.
1300.0	.5756E-0[illegible]	.7033E-01	.2547E-07	.7527E-02	0.	0.	0.	[illegible]	0.	0.
1080.0	.1749E+00	.5773E-01	.7759E-[illegible]	0.	0.	0.	0.	0.	0.	0.
860.0	.2554E+00	.1355E+00	.2475E-02	0.	0.	0.	0.	0.	0.	0.
640.0	.7725E+00	.2577E+00	0.	0.	0.	0.	0.	0.	0.	0.
420.0	.5853E+00	0.	0.	0.	0.	0.	0.	0.	0.	0.
200.0	.1554E-01	0.	0.	0.	0.	0.	0.	0.	0.	0.
-20.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-240.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-460.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-680.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-900.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1120.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1340.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1560.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1780.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2000.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
-2220.0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

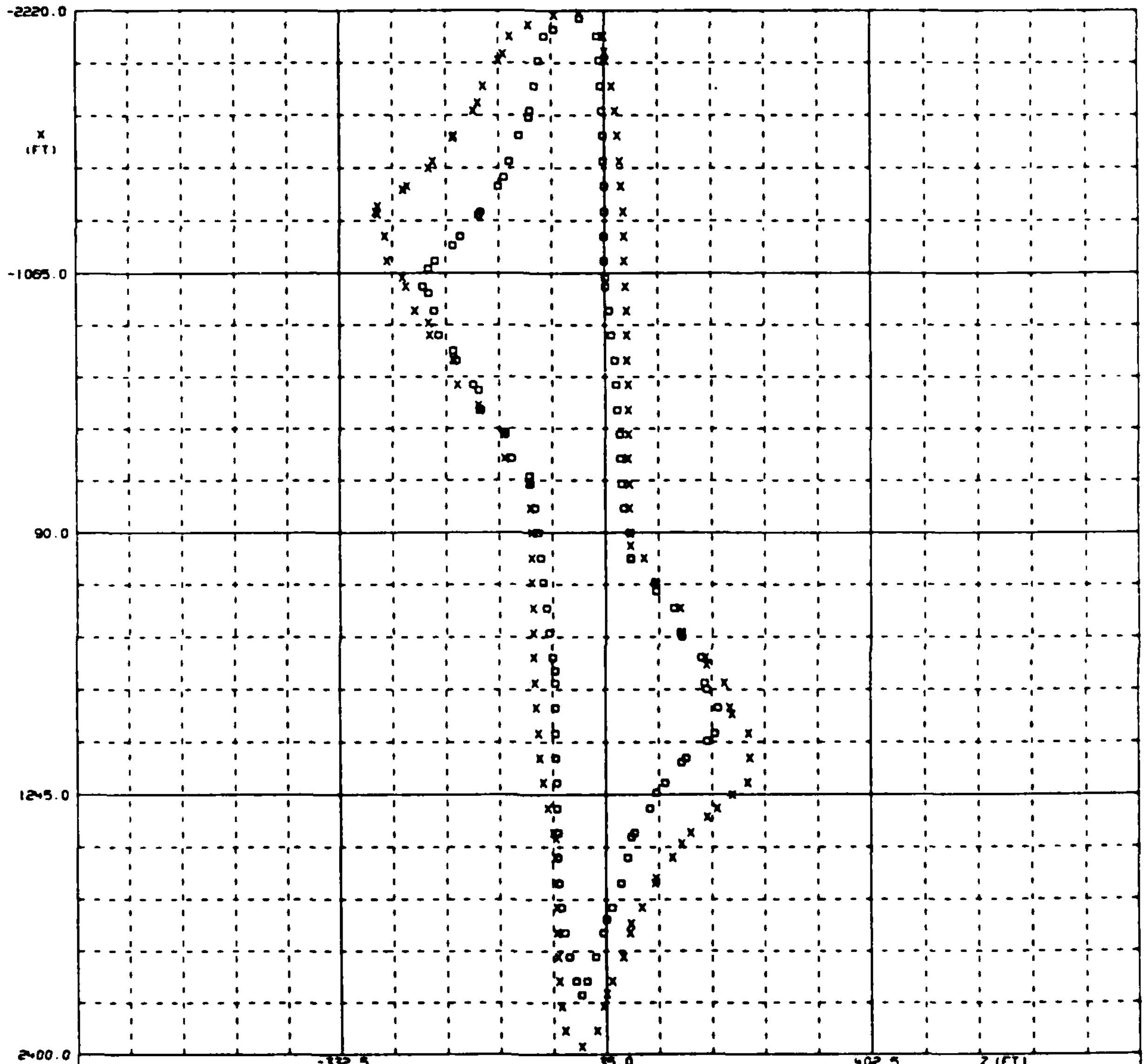
SAMPLE TEST CASE, TYPE2
SEED = 80000



SAMPLE TEST CASE. TYPE2
SEED = 35000




-2220.0
X
(FT)
-1065.0
90.0
1245.0
2400.0
-332.5
35.0
402.5
Z (FT)
TEST CASE REVISED LPHP
SEED = 30500.
PROBABILITY LIMIT(S)-
X IS 0.0100
□ IS 0.0500



TEST CASE REVISED LPHP
SEED = 80000.
PROBABILITY LIMIT(S)-
X IS 0.0100
O IS 0.0500

APPENDIX B

B.1 Safe Eye Exposure Distance Program, SEED

The interactive safe distance program, SEED, has been designed to provide a comprehensive estimate of safe distances and optical density requirements for a given set of conditions for a laser radiating as a point source.

The printed results include:

1. A list of the laser data and optical aid device specifications.
2. The Air Force Category of the laser as determined from the input characteristics.
3. The maximum permissible exposure levels for ocular exposures to point sources and extended sources, and skin exposure.
4. The optical density required for eyes and skin at the laser aperture.
5. The safe distance for unprotected eyes, not aided by an optical device.

*6. The safe distance for eyes aided by an unfiltered optical device.

*7. The safe distance for eyes unaided by an optical device and protected by eyewear of a specified optical density.

---

*Presentation of printed results determined by user option.

*8. The safe distance for eyes aided by an optical device employing a filter of a specified optical density.

*9. The optical density required for protective eyewear used at a given distance from the laser.

*10. The optical density requirement for an optical aid device filter used at a given distance from the laser.

11. Air-to-ground safe exposure distances for single and multiple pulse exposures for six atmosphere models. The distances are calculated for unprotected eyes, and for eyes aided by an unfiltered optical device.

12. Safe distance curves, in the form of deflection(from the vertical) angle vs distance, from a user-specified altitude. The curves are generated for six model atmospheres, single and multiple pulse, for unprotected eyes and eyes aided by an optical device.

Under previous studies, all safe distance values were converted to the metric system.

The calculations of items 4 through 10 are performed for single and repetitively pulsed lasers (single only, if CW laser), and presented in matrices of varying degrees of atmospheric turbulence and extinction conditions at sea level.

Program SEED does not currently compute the safe exposure distances or optical density values for lasers radiating as extended sources, or for diffuse reflection viewing.

*ibid

Maximum permissible exposure values for extended source viewing have, however, been included in the program for probable future use.

The basis for the calculations, and the tables utilized by program SEED were obtained primarily from AFOSH Standard 161-10, 30 May 1980. The reader is urged to obtain a copy of 161-10 for use in conjunction with this document. Tables 1 through 7 of 161-10 have been included in this document as a ready reference.

The input variables to program SEED consist of laser characteristics, optical aid device specifications, protective eyewear specifications, and/or user choices. Prior to execution of the program, the user should assemble the following information:

1. The wavelength at which the laser will operate (nanometers). (See page B-33 for list of usable wavelengths.)
2. The beam diameter, in centimeters, at the 1/e point.
3. The full angle beam divergence, in radians, at the 1/e point.
4. The laser output energy in Joules. For CW lasers, this value is the product of the laser power (watts) and the duration of operation in seconds.
5. The exposure duration, in seconds, for one execution of the program. The exposure duration is used as the train length in the calculation of a conversion factor (see Section B.1.1) for determining the

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maximum permissible exposure for multiple pulse exposures. For CW lasers, this is the duration of operation.

6. The pulse repetition frequency (PRF) of the laser (hertz). For CW lasers, the PRF is 0.0.
7. The pulse width, or single pulse exposure duration, in seconds. If the laser is operating as a CW laser, the user enters a single pulse time width of 0.0 E-15.
8. The optical density rating of the protective eyewear utilized. If this value is not available, the user may enter an arbitrary distance for calculation of the optical density necessary at that range.
9. Magnification, objective diameter (mm), and transmissivity of the optical aid device in use. The objective diameter is defined as the diameter of the lens which first receives radiation. If these values are not known, or no optical aid device is used, zeros may be entered, and the pertinent calculations are not performed.
10. The optical density rating of the filter used on the optical aid device. If this value is not known, or not applicable, the user may choose to enter a distance at which the required optical density for the filter will be calculated.

The last query of the user is whether he wishes to view the results of the program as it executes (O option), or

whether he wishes to view the results via the "PAGE" mode of the Cyber 176/CDC 6600 Operating System (1 Option). Each option has certain advantages. The real-time (0) option provides an immediate printout of all results generated, in a sequential, line-by-line stream. Disconnecting the output file (1) retains the printed file for viewing all, or only selected areas of the printed results. In addition, by issuing the command,

DISPOSE,OUTPUT,PR=CU1

the complete set of data is sent to an on-line printer for retrieval by the user.

Since the "PAGE" mode of the Cyber 176/CDC 6600 is capable of keying on unique character strings, page numbers have been included in the printed results. The page numbers are of the form, -N- where N is the number of the page. The reader is referred to Section B.3 for a description of the data contained on each page.

The OUTPUT file may also be viewed by executing the utility program, CDPK1. CDPK1 is an interactive program which allows the user to view (print) specified pages of the results generated by program SEED4, without incurring the interruptions produced by using "PAGE". See pages B-10 through B-10A for operating instructions and example.

Program SEED is executed interactively on the Cyber 176/CDC 6600 computer system from a remote terminal by the following commands:

```
ATTACH,SEED4,ID=XY,PW=----
CONNECT,INPUT,OUTPUT
SEED
```

where the password,PW, may be obtained from the range safety software control monitor.

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Each execution of program SEED4 (and subsequent versions) produces two disk files (SEDINP and TAPE10) which are used in the following manner.

SEDINP: This disk file contains the input data which was used for the (immediately) preceding execution of the program. The file is in the proper form to be used as input to another execution of program SEED4, and may be altered as desired by utilizing the EDITOR mode of the CDC 6600/Cyber 176 computer. Each input variable is identified by a descriptor printed to the right, to facilitate changing the values. File SEDINP must not exist as a local file when SEED4 is executed interactively.

TAPE10 This disk file contains the safe distance curve data seen on pages 8 through 11 of the tabular results, and is used as input to the Laser Safe Distance Curve plot program, LSDC1. Program LSDC1 (described in section B.2) will accept up to three adjoining files of TAPE10; however, the file must be renamed TAPE25 prior to execution of LSDC1.

An example for using these files in two executions of program SEED4 follows:

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```
COMMAND- ATTACH,SEED4,ID=XY,PW=
 AT CY= 001
COMMAND- CONNECT,INPUT,OUTPUT
COMMAND- SEED4
LASER SEED MATRIX COMPUTATION PROGRAM

   ENTRY OF ALL VALUES MAY BE DECIMAL OR EXPONENTIAL, AND MAY
   BE LOCATED ANYWHERE ON THE LINE.   THE EXAMPLE VALUES ARE
   NOT DEFAULT VALUES, WHICH MEANS THAT AN ENTRY IS REQUIRED
   FOR EACH QUERY.

TYPE IN THE LASER MODEL
FIRST RUN OF SEED4
WAVELENGTH (NANOMTRS.)
1064.
1064.
BEAM DIAMETER (CM)
2.5
2.5
BEAM DIVERGENCE (RAD.-FULL ANG.)
.000264
.264E-3
LASER POWER (JOULES)
0.11
.11
EXPOSURE DURATION (SEC.)
1.0
.025
PRF  (PPS)
8.0
8
SINGLE PULSE TIME (SEC) (0.0E-15 FOR C.W. LASERS)
.23E-07
.23E-7
ENTER A 1 OR 2
 1 CALCULATES THE O D REQUIRED FOR A GIVEN DISTANCE.
 2 CALCULATES THE SAFE DISTANCE FOR A GIVEN O D.
1
DISTANCE (M) FROM LASER TO VIEWER
1000.
2000
MAGNIFICATION OF THE OPTICAL AID DEVICE. (0.0 IF NONE)
7.
 0
ENTER AN AIRCRAFT HEIGHT (M)  FOR THE SAFE DISTANCE CURVES
2000.      (2000. M = 6562 FT)
3000
ENTER A 0 OR 1
0 IF YOU WISH TO VIEW ALL RESULTS REAL-TIME.
1 TO DISCONNECT THE FILE -OUTPUT- SO THAT RESULTS MAY BE SELECTIVELY PRINTED.
1
     STOP
      37000 MAXIMUM EXECUTION FL.
      0.573 CP SECONDS EXECUTION TIME.
```

Interactive execution of program SEED4

```
COMMAND- FILES
--LOCAL FILES--
 *TAPE8    *SEED4      OUTPUT     SEDINP     TAPE10
COMMAND- EDITOR
..E,SEDINP,S
..L,A


   100=FIRST RUN OF SEED4
   110=  .106400E+04              WAVELENGTH
   120=  .250000E+01              BEAM DIAM.
   130=  .264000E-03              DIVERGENCE
   140=  .110000E+00              POWER
   150=  .250000E-01              DURATION
   160=  .800000E+01              PRF
   170=  .230000E-07              PULSEWIDTH
   180= 1                         OD-DIS SEL
   190=  .200000E+04              DISTANCE
   200= 0.                        MAG O.A.D.
   210=  .300000E+04              A-C HEIGHT
   220= 1                         OUTPUT C-D
../.250000E-01/=/.100000E+01/,150,V
   150=  .100000E+01              DURATION
Y
      1 CHANGE(S)
../FIRST/=/SECOND/,100
      1 CHANGE(S)
..S,TWO,O,N
..B
COMMAND- BATCH,SEDINP,RENAME,FIRST
COMMAND- FILES
--LOCAL FILES--
 TAPE10             TWO        *TAPE8     *SEED4
 OUTPUT    FIRST
COMMAND- COPYCF,TAPE10,TEMP
COMMAND- RETURN,TAPE10
COMMAND- REWIND,SEED4
COMMAND- SEED4,TWO
     STOP
      37200 MAXIMUM EXECUTION FL.
      0.544 CP SECONDS EXECUTION TIME.
```

Note that files SEDINP and TAPE 10 have been created, and that TAPE8 (the attenuation file; LAZRCOF) has automatical been attached. File SEDINP contains input variables from the interactive execution on t previous page. Renaming of SEDINP prevents confusion of files.

Changing the exposure duration and title for the second SEED4 execution.

Renaming the SEDINP file generated by 1st execution of SEED4.

Preparation of data for LSDC1 run.

Performing 2nd execution of SEED 4.

```
COMMAND- COPYCF,TAPE10,TEMP
COMMAND- PAGE,TEMP
Ready..
1


FIRST RUN OF SEED4
 LASER ALTITUDE=   3000.00METERS.
 PAGE - 8-
    0.0   6119.9      0.0   6196.7      0.0   6196.8      0.0
   15.0   6117.0      0.0   6195.5      0.0   6195.6      0.0
   30.0   6107.4      0.0   6192.3      0.0   6192.4      0.0
   45.0   6086.8      0.0   6186.6      0.0   6186.7      0.0
   60.0   6043.6      0.0   6178.2      0.0   6178.3      0.0
   75.0   6068.2      0.0   6168.7      0.0   6168.9      0.0
   90.0   6030.7      0.0   6163.4      0.0   6163.6      0.0
  105.0   5941.6      0.0   6139.0      0.0   6139.3      0.0
Line     1
= SECON8


SECOND RUN OF SEED4
 LASER ALTITUDE=   3000.00METERS.
 PAGE - 8-
    0.0   6119.9      0.0   6196.7      0.0   6196.8      0.0
   15.0   6117.0      0.0   6195.5      0.0   6195.6      0.0
   30.0   6107.4      0.0   6192.3      0.0   6192.4      0.0
   45.0   6086.8      0.0   6186.6      0.0   6186.7      0.0
   60.0   6043.6      0.0   6178.2      0.0   6178.3      0.0
   75.0   6068.2      0.0   6168.7      0.0   6168.9      0.0
   90.0   6030.7      0.0   6163.4      0.0   6163.6      0.0
  105.0   5941.6      0.0   6139.0      0.0   6139.3      0.0
Line    61
E
COMMAND- REWIND,TEMP                 ] <-------- Positioning data on TAPE25 for
COMMAND- BATCH,TEMP,RENAME,TAPE25    ]           LSDC1 input.
COMMAND- FILES
--LOCAL FILES--
  SEDINP    TWO      *TAPE8    *SEED4     OUTPUT
  FIRST     TAPE25    TAPE10
```

```
COMMAND- ATTACH,LSDC1,ID=XY,PW=
 AT CY= 001
COMMAND- CONNECT,INPUT,OUTPUT
COMMAND- LSDC1,TAPE25


LASER SAFE DISTANCE CURVE PLOT PROGRAM (RUN# 1):

ENTER PLOT TITLE AND UP TO 3 LEGEND DESCRIPTERS (MAX OF 55 CHARACTERS EACH).
ENTER TITLE (ENTER STOP TO END PROGRAM)
?TEST CASE FOR LSDC1
   TITLE= TEST CASE FOR LSDC1
ENTER LEGEND(1) (ENTER 0, IF NOT APPLICABLE)
?FERRANTI LASER  .025 DURATION
   LEGEND(1)= FERRANTI LASER  .025 DURATION
ENTER LEGEND(2) (ENTER 0, IF NOT APPLICABLE)
?FERRANTI LASER   1.0 DURATION
   LEGEND(2)= FERRANTI LASER   1.0 DURATION
ENTER LEGEND(3) (ENTER 0, IF NOT APPLICABLE)
?0
   LEGEND(3)= 0
ENTER ATMOSPHERE MODEL NUMBER TO BE PLOTTED (1-6)
?3
   ATMOSPHERE MODEL NUMBER= 3
ENTER TYPE OF PULSE (1=SINGLE, 2=MULTIPLE, AND 3=CW)
?2
   TYPE OF PULSE= 2
ENTER VIEWING TYPE (1=NAKED EYE AND 2=OAD)
?1
   VIEWING TYPE= 1
```

Interactive execution of program LSDC1

```
LASER SAFE DISTANCE CURVE PLOT PROGRAM (RUN# 2):

ENTER PLOT TITLE AND UP TO 3 LEGEND DESCRIPTERS (MAX OF 55 CHARACTERS EACH).
ENTER TITLE (ENTER STOP TO END PROGRAM)
?STOP
   TITLE= STOP
     STOP
      36000 MAXIMUM EXECUTION FL.
      0.116 CP SECONDS EXECUTION TIME.
 FRAMES SC4020          0000000000000003
 SC4020 RECORDS         0000000000000002
COMMAND- DISPOSE,FILMPL,FL=CU1
```

Obtaining S.C.4020 plot from computer center.

The user should note that if the option to disconnect the output file is chosen, and subsequent interactive executions of SEED are to follow,the commands

```
CONNECT,OUTPUT
REWIND,SEED4
RETURN,SEDINP or
BATCH,SEDINP,RENAME,lfn
```

must be given prior to execution.

A flow diagram of the program is shown in Figure B.1.1.

UTILITY PROGRAM CDPK1

Program CDPK1 is an interactive program designed specifically for printing user-specified pages of the OUTPUT file generated by program SEED4. The files necessary for execution of CDPK1 are "CONNECTED" from within the program; therefore, the only commands required for initiation are:

```
ATTACH,CDPK1,ID=XY,PW=----
CDPK1
```

The user is asked for the number of pages he wishes to be printed, and the page numbers of those pages. (See example, Page B-10A)

Since program CDPK1 operates on the local file OUTPUT, and since multiple executions of program SEED4 can "stack" the OUTPUT file, it behooves the user to perform some action on OUTPUT after executing CDPK1. Some suggested action commands are:

BATCH,OUTPUT,RENAME,lfn	(Changes the name of OUTPUT)
BATCH,OUTPUT,PRINT	(Removes OUTPUT from local files, and causes copy to be printed at the computer center.
REWIND,OUTPUT, COPYCF,OUTPUT,lfn	(Copies OUTPUT into another file. This is used for "stacking" multiple OUTPUTS, so that one PRINT command may be used for all runs.)
DISCARD,OUTPUT	(Removes the OUTPUT file from local files.)

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```
COMMAND- FILES
--LOCAL FILES--
 *TAPE8    *SEED4     OUTPUT    SEDINP    TAPE10
COMMAND- ATTACH,CDPK1,ID=XY,PW=
 AT CY= 001
COMMAND- CDPK1
 ENTER # OF PAGES WANTED TO BE PRINTED?1
    # OF PAGES= 1
 ENTER THE 1 PAGE NUMBERS IN INCREASING VALUE?2
    PAGE NUMBERS= 2
PAGE - 2-

         SINGLE PULSE SAFE EYE EXPOSURE DISTANCES (METERS)

                                   OCULAR POINT   EXTENDED S.    SKIN
 M.P.E. FOR .230000E-07 SECS      .500000E-05    .142193E+00    .100000E+00
 O.D. AT LASER APERTURE             3.65                           .00

              EXTINCTION   TURBULENCE-
              COEFFICIENT  STRONG                                      WEAK
                        .1000E-12 .1000E-13 .1000E-14 .1000E-15 .1000E-16

                0.000 VACUUM
 UNPROTECTED EYE SEED        6244.9     6244.9     6244.9     6244.9     6244.9
 EYE     O D AT  2000. M       .96        .96        .96        .96        .96
                 .001 PURE AIR
 UNPROTECTED EYE SEED        4098.6     6032.1     6219.4     6225.0     6225.2
 EYE     O D AT  2000. M       .81        .96        .96        .96        .96
                 .088 VERY CLEAR
 UNPROTECTED EYE SEED        3657.8     4900.6     4991.5     4994.2     4994.2
 EYE     O D AT  2000. M       .73        .88        .89        .89        .89
                 .120 CLEAR DAY
 UNPROTECTED EYE SEED        3525.3     4613.5     4687.8     4689.9     4690.0
 EYE     O D AT  2000. M       .71        .85        .86        .86        .86
                 .410 LIGHT HAZE
 UNPROTECTED EYE SEED        2715.5     3174.2     3196.4     3197.0     3197.1
 EYE     O D AT  2000. M       .45        .60        .61        .61        .61
                1.150 HAZE
 UNPROTECTED EYE SEED        1817.6     1954.5     1959.6     1959.7     1959.7
 EYE     O D AT  2000. M       .00        .00        .00        .00        .00
                2.950 THIN FOG
 UNPROTECTED EYE SEED        1087.8     1119.1     1120.1     1120.1     1120.1
 EYE     O D AT  2000. M       .00        .00        .00        .00        .00
                7.820 LIGHT FOG
 UNPROTECTED EYE SEED         569.6      574.8      574.9      574.9      574.9
 EYE     O D AT  2000. M       .00        .00        .00        .00        .00
               19.600 MEDIUM FOG
 UNPROTECTED EYE SEED         286.0      286.8      286.8      286.8      286.8
 EYE     O D AT  2000. M       .00        .00        .00        .00        .00
               78.200 THICK FOG
 UNPROTECTED EYE SEED          90.4       90.4       90.4       90.4       90.4
 EYE     O D AT  2000. M       .00        .00        .00        .00        .00


     STOP
      24500 MAXIMUM EXECUTION FL.
      0.101 CP SECONDS EXECUTION TIME.
```

Interactive execution of program CDPK1. Underlined values are user responses.

SEED4 Program Flow Diagram

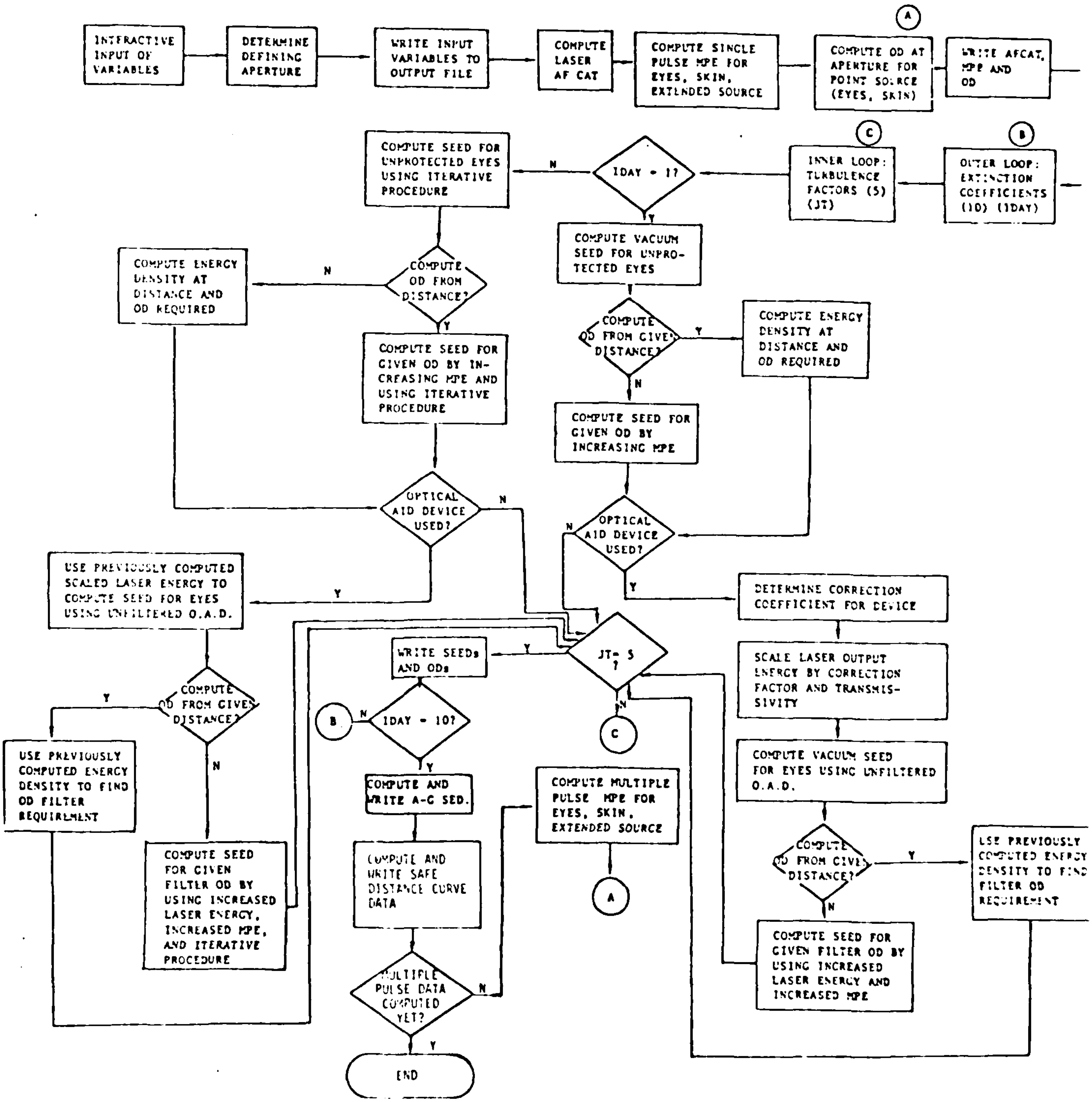

Figure B.1.1

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B.1.1 Determination of the Laser Category

The determination of the Air Force Category (AF CAT) code by program SEED follows the criteria outlined in Appendix III, Section B, of AFOSH Standard 161-10 for lasers radiating as point sources.

The parameters necessary to determine the AF CAT code are either input by the user, computed from values given by the user, or derived from tables incorporated into the program. The parameters include:

- The wavelength (input value).
- The single pulse time width (input value).
- The train length (exposure duration) (input value).
- The pulse separation (computed).
- The radiant exposure (computed).
- The emitted energy (computed).
- The maximum permissible exposure (table look-up).
- The appropriate defining aperture (table look-up).

Certain lasers are capable of operating at more than one wavelength or power setting, and therefore may attain varying degrees of hazardous operation. Since program SEED uses data provided by the user, the definition of the category code derived by the program represents the evaluation with respect to those input parameters, and does not necessarily represent the code for the most hazardous mode of operation.

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The derivation of the AF CAT code is made by comparison of a permissible exposure level for ocular exposure to a point source, and a radiant exposure for a specified time period.

The methodology for calculating the maximum permissible exposures for a single pulse or CW laser, and a repetitively pulsed laser (if the laser is not operating as a continuous wave laser) is described in Section B.1.2.

There are two radiant exposure calculations required for determining the laser category. The total radiant exposure (H_T) is the maximum energy (Q_T) in the beam within a certain time interval, divided by the appropriate defining aperture. The time interval to be used in the calculation of H_T is wavelength dependent and varies for each AF CAT code. The time intervals are shown in Table 6, Appendix III of AFOSH Standard 161-10 (pg B-48 of this document), and defined below:

Symbol	Definition
PW	The single pulse time width (sec.) or exposure duration (sec.) for multiple pulse operation. (User given values.)
Max_{Top}	The maximum on-time of the laser during an appropriate 8 hour period (Max_{Top}=30000 sec./PW).
t_{max}	Set to 30000 sec.

The calculation of H_T is made from the equation

$$H_T = Q_{T(time)}/A_{ap}$$

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where

$Q_{T(time)}$ is the total energy (Joules) emitted within the time period defined in Table 6.

A_{ap} is the area of the defining aperture (cm^2) shown in Appendix III of AFOSH 161-10. (See also Table B.1.3.1 of this document.)

The radiant exposure (H) is the cumulative peak radiant exposure in the beam for the time interval specified in Table 6 (pg B-48), and is used to determine an upper limit for AF CAT C lasers. Since H represents the accumulatic.ı of energy during the maximum possible operating time inherent in the laser, or 8 hours of operation, the equation for computing H is given by:

$H = Q_{t_{max}}/A_b$ or $H = Q_t/A_b$ for exposure durations less than .25 seconds.

where

$Q_{t_{max}}$ is the energy (Joules) accumulated in the t_{max} time period.

Q_t is the energy (J) accumulated in .25 sec. (blink response).

A_b is the area of the laser beam at the aperature.

Once the calculations for the radiant exposures have been performed, and the MPE derived, the comparisons to determine the appropriate category for the laser operating conditions may begin. The comparisons are made in a top-down fashion; i.e., for the appropriate wavelength, the comparisons for category A are made, then category B if the criteria for category A are not met, then category C, etc.

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If the MPE cannot be determined from the input data given by the user, the program indicates an AF CAT D laser, prints the message "UNKNOWN M.P.E" and terminates.

If the laser is a point source laser, operating in a multiple pulse mode (PRF > 0.0), the calculation of the AF category is repeated, using a multiple pulse MPE for the calculations. The AF CAT designation is the more hazardous of the two category determinations.

B.1.2 Maximum Permissible Exposure Determination

The permissible exposure levels of energy incident upon human eyes and skin, and the energy received by the eyes from extended source viewing, or viewing a diffusely reflecting surface, are defined by protection standard tables (Table 1, 2 and 3) in Appendix III of AFOSH Standard 161-10 (Pages B-41 through B-44 of this document). Determinations of the maximum permissible exposures (MPE) due to a single pulse for eyes, skin and extended source viewing are made from look-ups in these tables, using the operating wavelength of the laser, and the exposure duration of a single pulse. (Single pulse time width.)

Multiple pulse permissible exposure levels for eyes, skin and extended source viewing are computed from the product of one of three single pulse MPE's and a conversion factor based upon Table 5 in Appendix III of AFOSH 161-10 (page B-46 of this document). The calculations of the appropriate single pulse MPE, the conversion factor, and the resulting multiple pulse MPE's for eyes, skin and extended source viewing involve seven steps, as follows:

1. The pulse separation, PS, is computed from the equation : PS = (1.0/PRF)-PW

where PRF is the pulse repetition frequency of the laser, and PW is the time duration of a single pulse from the laser (single pulse time width).

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2. The number of single pulses contained in the user-given exposure duration for one execution of the program is given by: N = PRF*(TL-PW) + 1

where TL is the train length, or, exposure duration.

3. The total amount of time, TOT, that the laser is on (emitting single pulses) is the summation of all single pulse durations contained in the train length: TOT = PW*N

4. Using the pulse separation (PS) and the operating wavelength of the laser, the appropriate applicable exposure durations for pulsewidth criteria and for pulse train criteria are determined.

5. Maximum permissible exposures for the pulse train exposure duration (TOT or TL) are determined for eyes, skin and extended source viewing from Tables 1, 2 and 3 (Pages B-41 through B-44). (The MPE's for pulsewidth exposure durations are the single pulse MPE's described in Paragraph 1.)

6. The conversion factors for pulsewidth criteria and pulse train criteria for the appropriate pulse separation are multiplied by the respective applicable exposure duration.

7. The maximum permissible exposure for multiple pulse exposures is the least of the two products in Step 6.

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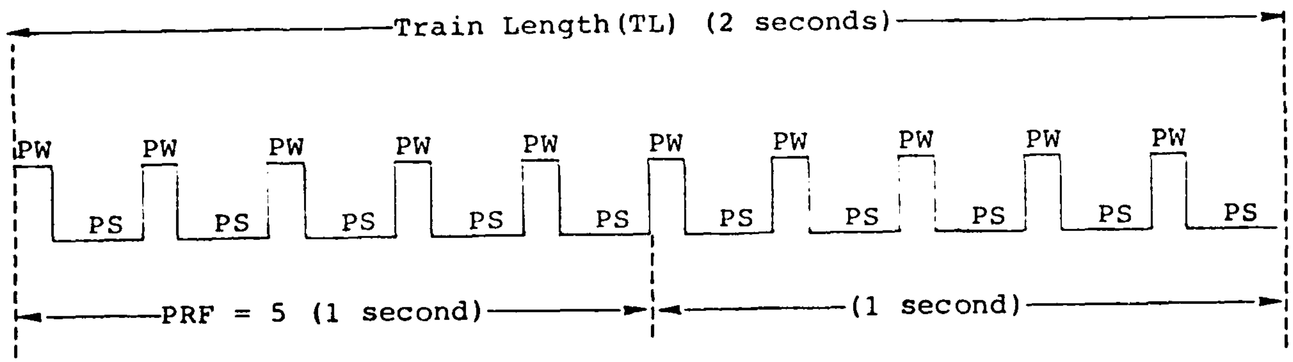
A pictorial representation of the elements involved in the multiple pulse MPE calculation is shown in Figure B.1.2.1.

Figure B.1.2.1

Simple Periodic Pulses



PW = The single pulse time width. (User input)

TL = The exposure duration for one execution of SEED. (User input)

N = PRF x (TL - PW) + 1

TOT = N x PW

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(Revised 03/01/82)

B.1.3 SEED Calculation

The safe eye exposure distance, R_S, is calculated from the equation

$$\frac{\pi Q}{4U} = e^{-\mu R_s}/(D_b + 2R_s\phi)^2 \; (1 + B_T) \qquad \text{(B.1.3.1)}$$

(see p. 3-15 of Reference 2)

where

Q = the Maximum Permissible Exposure (MPE) (J/cm^2) (See Section B.1.2)

U = the pulse energy output by the laser (Joules)

μ = the atmospheric extinction coefficients for 9 variations of weather. (Values for μ used by the program are listed in Table B.1.3.1) (cm^{-1})

D_b = the laser beam diameter at the source (cm)

ϕ = the beam divergence half angle (radians)

B_T = the turbulence induced beam spread factor for 5 variations from strong to weak

The quantity B_T is computed from the equation

$$B_T \cong 0.11 \; (D_b/r_o)^{2.6} \qquad \text{(B.1.3.2)}$$

which approximates the curve found on p 3-12 of Reference 2.

In this equation, r_o is computed by

$$r_o = 0.334 \; (C_n^2 R_s \lambda^{-2})^{-3/5} \qquad \text{(B.1.3.3)}$$

where

C_n = the atmospheric turbulence refractive index

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Table B.1.3.1

Weather Condition	Attenuation Coefficient (μ) (km^{-1}) .55 $\mu m \lambda$	1.06 $\mu m \lambda$
Pure Air	0.0141	0.001
Very Clear	0.0780	0.088
Clear Day	0.3910	0.120
Light Haze	0.9540	0.410
Haze	1.9600	1.150
Thin Fog	3.9100	2.950
Light Fog	7.8200	7.820
Medium Fog	19.6000	19.600
Thick Fog	78.2000	78.200

Obtained from data presented in Reference 2, pgs 3-6, 3-7. Lasers operating at $\lambda < 800.0$ use coefficients for .55 μm, while lasers operating at $\lambda \geq 800.0$ use coefficients for 1.06 μm.

Sea Level Attenuation Coefficients for .55 μm and 1.06 μm Wavelength Lasers

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R_s = the SEED range

λ = the wavelength of the laser

The values of C_n^2 range from 10.E $-17m^{-2/3}$ or smaller for very weak turbulence to 10.E $-13m^{-2/3}$ or larger for very strong turbulence. The former value is typical of a dawn or dusk conditions, while the latter is more likely to occur near solar noon.

Equation B.1.3.1 may be solved for the SEED as follows:

(1) The elements of eqn B.1.3.1 should be scaled to consistent dimensions:

Express D_b and λ in cm, C_n^2 in $cm^{-2/3}$, μ in cm^{-1}, 2ϕ in radians, U in Joules and Q in J/cm^2.

The SEED, R_s, (in feet) is obtained by use of a Newton iteration:

(2) Let $C_1 = 4U/\pi Q$

$$C_2 = (.11)D_b/.334)^{2.6}(C_n^2/\lambda^2)^{1.56}$$

$$R_O = (\sqrt{C_1}-D_b)/2\phi$$

$$S_O = D_b + 2\phi R_O$$

$$T_O = 1 + C_2 R_O^{1.56}$$

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(3) For $n = 0,1,2...$

$$S_n = D_b + 2\phi R_n$$

$$T_n = 1 + C_2 R_n^{1.56}$$

$$f_n = S_n^2 T_n + 4\phi S_n T_n + 1.56\ S_n^2 (T_n - 1)/R_n)\ \mathrm{Exp}\ (\mu R_n)$$

(4) $R_{n+1} = R_n - f_n/f_n'$

(5) Stop the process when $|R_{n+1} - R_n| < 100$

(6) Then

$$R_s = (.0328084) R_{n+1}$$

The iterative process is repeated, entering each of the nine atmospheric extinction coefficients (μ) for each of the five turbulence induced beam spread factors (B_T) to form the SEED matrix for single pulse laser operations. Safe eye exposure distances for a vacuum ($B_T = \mu = 0.0$) are included in the matrix.

Calculation of a safe eye exposure distance is performed from one to four times, depending upon user option choices. The SEED for an unprotected eye is always calculated, as outlined in Equations B.1.3.1 through B.1.3.3. If the option to compute the safe distance for eyes protected by eyewear of a given optical density is chosen, an increased permissible exposure level is calculated (see Section B.1.4) and used in Equation B.1.3.1.

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Entry of specifications for an optical aid device generates safe eye exposure distances to be observed while utilizing the device without a filter. Equation B.1.3.1 is again used, with the pulse energy of the laser, U, scaled by the magnification properties of the device and the transmissivity inherent in the design of the device for the operating wavelength of the laser. A more complete discussion of the determination of the coefficient is presented in Section B.1.4.4.

Computation of a safe eye exposure distance to be observed while using an optical aid device equipped with a filter of known optical density requires the use of an increased permissible exposure level (Q', Section B.1.4.2), and a scaled laser pulse energy (U', Section B.1.4.4) in Equation B.1.3.1.

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B.1.4 Optical Density (OD) Calculation

Determination of the OD required for clothing, protective eyewear, or optical aid device filters to be used with a specific laser is based upon the equation

$$O.D. = \log_{10} \left(\frac{H}{MPE}\right) \qquad (B.1.4.1)$$

where

MPE is the maximum permissible exposure,

and

H is the peak radiant exposure at a distance from the laser.

The peak radiant exposure is computed from the equation

$$H = \frac{4U\ e^{-\mu R}}{\pi\ (A + R\ (2\phi))^2\ (1.0+B_T)} \qquad (B.1.4.2)$$

where

U = the pulse energy of the laser,

μ = the atmospheric extinction coefficient,

ϕ = the beam divergence half angle,

B_T = a turbulence-induced beam spread factor,

R = the distance of concern,

A = a diameter. The value of the diameter depends upon whether the calculation of H is performed for an ocular exposure, a skin exposure, or for an optical aid device. The criteria for determining the value of A are shown in the following table.

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Table B.1.4.1

Ocular Exposure:

The value of A is the laser beam diameter at the corneal plane, or the defining aperture, whichever is greater. The defining apertures for laser wavelengths from 200 nm to 10^6 nm are listed below.

Laser Wavelength (nm)	Defining Aperture
$200 \leq \lambda \leq 400$	.1 cm
$400 < \lambda \leq 1400$	.7 cm
$1400 < \lambda \leq 10^5$	.1 cm
$10^5 < \lambda \leq 10^6$	1.0 cm

Skin Exposure:

The diameter of the laser beam at the skin surface is used in all calculations.

Optical Aid Devices:

The value of A is the greater of: (a) the laser beam diameter at the objective aperture of the optical aid device (b) the diameter of the objective aperture.

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Optical density protection criteria for human eyes and unprotected skin are calculated at the laser aperture for single and multiple pulse modes of operation.

The user of program SEED has four options pertaining to optical density calculations:

- Determination of the OD required for protective eyewear at a given distance from the laser.
- Given the OD rating of protective eyewear, calculation of a safe eye distance from the laser.
- Determination of the OD for a filter employed by an optical aid device located at a given distance from the laser.
- Given the filter OD rating for an optical aid device, calculation of a safe distance from the laser for use of the device.

The variations in the elements of the equations (B.1.4.1 and B.1.4.2) which are necessary for each of the four options are discussed in the following subsections.

B.1.4.1 <u>OD Calculation for Protective Eyewear</u>

The option to calculate the optical density necessary for protective eyewear at a specified distance from the laser affects two elements of equation B.1.4.2. R, the distance of concern, is assigned the value given by the user. A beam diameter at R, based upon the beam diameter of the laser

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and the divergence of the beam, is computed from the equation

$$A_R = D_b + R\ (2\phi)$$

where

D_b is the laser beam diameter,

ϕ is the beam divergence half angle.

The comparison of A_R for ocular exposure as shown in Table B.1.4.1 is made to determine the diameter, A, used in equation B.1.4.2.

Using the value of H, calculated from the appropriate value of A in equation B.1.4.2, the optical density rating for protective eyewear is determined by equation B.1.4.1.

B.1.4.2 <u>Safe Eye Distance for Protective Eyewear of Specified OD</u>

When the optical density value for protective eyewear is given, equation B.1.4.1 is used to find the level of radiant exposure that is permissible on the eyewear to maintain ocular safety.

$$H = (10^{OD})\ (MPE) \qquad (B.1.4.3)$$

Since H now represents a modified permissible exposure level (Q'), the value may be substituted for the MPE (Q) of equation B.1.3.1, or:

$$\frac{\pi Q'}{4U} = e^{-\mu R_s} / \ (D_b + 2R_s\ \phi)^2\ (1 + B_T)$$

The safe eye exposure distance, R_s, is then computed by the iterative procedure described in Section B.1.3.

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B.1.4.3 Calculation of OD for Optical Aid Device Filter

When an optical aid device is employed, and the option to compute the optical density filter necessary for ocular protection at distance R is chosen, the peak radiant exposure, H, is computed from equation B.1.4.2. As in Section B.1.4.1, a beam diameter at distance R is computed, and the appropriate value of A determined from the criteria in Table B.1.4.1.

The optical density rating for the filter is determined from equation B.1.4.1, using the computed value of H and the permissible exposure level.

B.1.4.4 Safe Eye Distance for Optical Aid Devices Employing Filters of a Specified OD

The methodology described in Section B.1.4.2 for determining a safe distance from the laser for eyes protected by eyewear of a specified optical density is also employed to calculate the safe eye distance when using an optical aid device equipped with a filter of known optical density rating. As before, equation B.1.4.3 calculates a modified permissible exposure level (Q'), which is substituted for Q in equation B.1.3.1 (pg B-20).

Since the use of optical viewing instruments may increase the radiant exposure received by the eye, it is necessary to further modify equation B.1.3.1 to express the change in energy transmitted through the instrument. The energy change is a function of the magnification of the device

and the transmissivity inherent in the device for the operating wavelength of the laser and is represented by the equation

$$U' = (U)(T)(G)$$

where

U = the output energy from the laser,

T = the transmissivity of the instrument for the operating wavelength,

G = a correction factor based upon the magnification, exit (eye end) beam diameter, the entry (objective end) beam diameter, and the operating wavelength of the laser.

The quantity G is determined by program SEED as follows:

1. When the laser operates at wavelengths between 400 and 1400 nanometers, G may assume one of three values as follows:

   (a) $G = M^2$ when $d_e \geq 0.7$ cm

   (b) $G = (d_o/0.7)^2$ when $d_e < 0.7$ cm and $d_o > 0.7$ cm

   (c) $G = 1.0$ when $d_e < 0.7$ cm and $d_o \leq 0.7$ cm

   For these criteria:

   M = the magnification of the system

   d_o = the diameter (cm) of the beam entering the optical system. (The maximum value d_o may attain is the diameter of the objective.)

   d_e = the diameter of the beam leaving the system: $d_e = d_o/M$

2. When the laser operates at wavelengths from 200 to 400 nanometers, or from 1400 to 10^6 nanometers,

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$G = M^2$.

Equation B.1.3.1 becomes:

$$\frac{\pi Q'}{4U'} = e^{-\mu R_s} / (D_b + 2R_s\phi)^2 \; (1 + B_T)$$

and the iterative procedure described in Section B.1.3 calculates the safe eye exposure distance for persons using an optical viewing instrument.

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B.1.5 Air-to-Ground Safe Exposure Distances

The matrices of altitudes vs safe exposure distances (SED) produced by program SEED indicate the attenuation of the laser beam due to atmospheric conditions as the beam travels to the ground from 1 km levels of altitude.

The attenuation of the beam is caused by aerosol and molecular scattering and absorption parameters which are derived from the various gases and particles that compose the atmosphere. Since derivation of the parameters is rather complex, and because the atmospheric components vary with time and position, model atmospheres are ordinarily used to calculate the beam transmission through layers of air. One of the models - midlatitude, summer, clear day - was taken from AFCRL-72-0497, and modified for presentation in AFOSH 161-10 as extinction coefficients for vertical, 1000 meter layers of atmosphere, for twelve wavelengths. The data in this table have been incorporated into program SEED for calculation of air-to-ground safe exposure distances, and are listed in this document on pages B-51 and B-52 (Table 7).

Under a previous task, five additional model atmospheres (Midlatitude, Summer, Clear Day Model, 1980 data; Eglin Winter; Eglin Spring; Eglin Summer; Eglin Fall) were generated for 27 wavelengths, and stored in the Eglin computer system disk files (see page B-5).

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Air-to-Ground safe exposure distances, based upon attenuation of the beam by these atmosphere models, are calculated and presented on the tabular output.

The user of program SEED should note that one of the following wavelengths must be entered into the data base.

$\lambda_{\mu m}$	$\lambda_{\mu m}$	$\lambda_{\mu m}$	$\lambda_{\mu m}$
772.9767	5.5000	1.0600	.7793
336.9953	4.0000	.9100	.7525
118.6000	3.6000	.9040	.6943
118.2998	3.3920	.9000	.6500
27.9000	3.1000	.8600	.6328
10.6000	1.5360	.8500	.6300
10.5910	1.0640	.8000	

The transmission through the atmosphere is determined from the summation of the extinction coefficients multiplied by the path length in the layer, or:

$$T_{\lambda,R} = \exp -\sum_{j=1}^{n} \left[\left(\mu_{\lambda(j)} \quad r_{(j)} \right) \right]$$

where

$\mu_{\lambda(j)}$ = the extinction coefficient (cm^{-1}) for wavelength λ, jth atmospheric layer,

$r_{(j)}$ = the path length in the jth layer (cm), and

$R = \sum_{j=1}^{n} h_{(j)} \sec \theta$

where

$h_{(j)}$ = the vertical distance of propagation in the jth layer, and

$\sec \theta$ = the angle between the beam and the vertical.

The air-to-ground safe distances are computed by an iterative procedure described in AFOSH 161-10 (pages IV-9,10) from the equation:

$$\text{SED} = \left(\frac{\sqrt{4(U\ T_{\lambda,R})/\pi\ Q}}{2\phi}\right) - D_b$$

where

U = the laser output power (Joules)

Q = the Maximum Permissible Exposure (J/cm^2),

D_b = the beam diameter (cm) at the aperture, and

ϕ = the beam divergence half angle (radians).

(Note: ϕ is assumed to be small so that $\tan \phi \approx \phi$.)

Because the laser may operate at wavelengths other than those specified by the extinction coefficient tables, and because the air-to-ground calculations are performed for each 1000 meter step from 1 through 20 km, and require a deflection angle (ϕ) which varies for each iteration of R, the operation of program SEED is somewhat more complex than the procedure outlined in AFOSH 161-10. A step by step description of the methodology employed by program SEED follows:

1. A comparison of the input wavelength, and the table of wavelengths given in AFOSH 161-10 (Page B-51 of this report) is made. The extinction coefficients for the wavelength numerically closest to the input wavelength are used. Extinction coefficients for other atmosphere models are read in from disk file LAZRCOF.

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2. The initial SED is assigned the value of the vacuum SEED computed for sea level safe exposure distances. ($SED_{init.} = R_{MAX}$)

3. Using the vacuum SEED, a trial total path length, R_n, for the jth atmospheric layer is determined. (see 161-10, pg IV-10, step b.)

4. The vertical path length (HT) from the next lower layer to the ground is calculated.

5. The cosine of the deflection angle θ is calculated from the division of the vertical distance by the total path length:

$$\cos \theta = HT/R_n$$

If the vertical path length is larger than R_n, the next level down is used for HT.

6. The path length within the layer is computed from the width of the layer (1000 meters) divided by the cosine of the deflection angle:

$$PATH = 1000 \text{ m}/\cos \theta$$

7. The products of the extinction coefficients and the path lengths for layers 1 through HT are summed, and a SED calculated.

8. If the difference between the SED calculated in Step 7 and the SED computed by Step 3 is less than 100 cm, the solution for the jth layer safe exposure distance is considered final.

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Steps 1 through 8 are repeated for each 1000 meter level, beginning with 20 km and ending at 1 km. The calculation of a sea level SED (0 km) is performed by the iterative procedure described in Section B.1.3, setting the turbulence coefficient B_T = 1.0E-17, and assigning the 0 km extinction coefficient value to μ.

The air-to-ground safe exposure distances are calculated for single and multiple pulse exposures for the six model atmospheres. The safe exposure distances are generated for unprotected eyes, and eyes aided by an unfiltered optical viewing instrument.

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B.1.6 Safe Exposure Distance Curves

The safe exposure distance curves calculated by the program utilize the algorithms and techniques outlined in section B.1.5 with three exceptions:

1. The safe distances computed emanate from one user-supplied altitude, rather than from 1 km layers directed downward.
2. The angle of deflection from the vertical is not calculated (see item 5 of program methodology in section B.1.5, page B-35) but is held constant for each safe exposure distance computation. Safe distances are calculated at 15 degree increments of deflection from 0 degrees to 180 degrees.
3. The iterative procedure described in section B.1.3 is used to calculate the safe exposure distance for 90 degrees. In this case, the turbulence coefficient, B_T, is set to 1.0E-17, and μ, the extinction coefficient is assigned the value for the atmospheric layer corresponding to the user-supplied laser altitude.

The safe distance curves are presented in the form of angle of deflection vs safe distance, for the six model atmospheres, single and multiple pulse, for unprotected eyes, and eyes aided by an optical device. Termination of the beam of hazardous radiation by intersection with the ground is indicated by a negative sign.

The safe distance curves data are written to a disk file (TAPE10) for plotting by the Laser Safe Distance Curve plot program, LSDC.

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B.2 Laser Safe Distance Curve Plot Program (LSDC)

The interactive computer program designed to plot the safe distance curves generated by program SEED4 is initiated from a remote terminal by the following commands:

```
ATTACH,LSDC1,ID=XY,PW=---
CONNECT,INPUT,OUTPUT
LSDC1,TAPE25
```

where

the password, PW, may be obtained from the Range Safety software control monitor, and TAPE25 is the local file containing the safe distance curve data generated by up to three executions of program SEED4. (Note: Due to the CDC 6600/Cyber 176 operating system, the input data must be named TAPE25.)

The user is requested to enter a plot title, and descriptors for the three (or less) curves that will be plotted. The descriptors should coincide with the structure of the input data; i.e., legend number 1 is descriptive of the first execution of program SEED4 which was copied onto the input disk file, legend number 2, the second execution, etc.

The atmosphere numbers correspond to the atmosphere models listed on the tabular results, reading from left to right:

1 = AFOSH DATA (1972)

2 = Standard 1980

3 = Eglin Summer

4 = Eglin Winter

5 = Eglin Spring

6 = Eglin Fall

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The choice of single or multiple pulse, unprotected eye or optically aided eyes applies to all sets of safe distance curve data contained on the input file. These choices - the model, pulse type, and viewing mode - are automatically produced on the plot, so that the user need not reiterate this information in the title or legends.

Program LSDC will generate one plot frame per series of queries, and will continue to recycle until (a) the user enters STOP for a title, or (b) the computer time limit is exceeded.

B.3 Sample Executions of Programs SEED4 and LSDCl

The following sample executions of program SEED4 and LSDCl are included to illustrate the interactive input queries, and the results produced by the program for responses to the queries.

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Example 1

The purpose of Example 1 is to illustrate the following points:

1. The method for obtaining the data file that contains the laser coefficients for six atmosphere models, 27 wavelengths (file LAZRCOF).

2. The interactive queries from SEED4, and the user responses.

3. An example of transmission noise on the line. (Line 30, next page.)

4. The entire printout generated by program SEED4. (Response to final query is 0; view all results real-time.)

5. The files generated by execution of program SEED4. (Last page of Example 1.)

Example 1

Note: For illustrative purposes only- do not include in execution steps

```
COMMAND- CONNECT,INPUT,OUTPUT
COMMAND- ATTACH,SEED4,ID=XY,PW=
 AT CY= 001
COMMAND- ATTACH,DATAFL,ID=VP,PW=
 AT CY= 002
COMMAND- BEGIN,GET,DATAFL,LAZRCOF
 AT CY= 019
  UPDATE COMPLETE.
COMMAND- REWINDX
COMMAND- SEED4
LASER SEED MATRIX COMPUTATION PROGRAM

   ENTRY OF ALL VALUES MAY BE DECIMAL OR EXPONENTIAL, AND MAY
   BE LOCATED ANYWHERE ON THE LINE.   THE EXAMPLE VALUES ARE
   NOT DEFAULT VALUES, WHICH MEANS THAT AN ENTRY IS REQUIRED
   FOR EACH QUERY.

TYPE IN THE LASER MODEL

WAVELENGTH (NANOMTRS.)
1064.
1064.
BEAM DIAMETER (CM)
2.5
5.38
BEAM DIVERGENCE (RAD.-FULL ANG.)
.000264
2.64e-4
LASER POWER (JOULES)
0.11
.125.
    .125.<-ERROR IN COL.  5, RETYPE RECORD FROM THIS FIELD.125
EXPOSURE DURATION (SEC.)
1.0
1.
PRF  (PPS)
8.0
30.
SINGLE PULSE TIME (SEC) (0.0E-15 FOR C.W. LASERS)
.23E-07
1.5e-8
ENTER A 1 OR 2
 1 CALCULATES THE O D REQUIRED FOR A GIVEN DISTANCE.
 2 CALCULATES THE SAFE DISTANCE FOR A GIVEN O D.
1
DISTANCE (M) FROM LASER TO VIEWER
1000.
2500.
```

```
MAGNIFICATION OF THE OPTICAL AID DEVICE. (0.0 IF NONE)
7.
7.
DIAMETER(MM) OF THE OBJECTIVE OF THE OPTICAL AID DEVICE.
50.
50.
TRANSMISSION OF O.A.D. FOR WAVELENGTH 1064.
   (1.0 IF UNWANTED OR UNKNOWN.)
0.78
1.
ENTER A 1 OR 2
 1 CALCULATES THE O D REQUIRED FOR A GIVEN DISTANCE.
 2 CALCULATES THE SAFE DISTANCE FOR A GIVEN O D.
1
DISTANCE (M) FROM LASER TO VIEWER
1000.
2800
ENTER AN AIRCRAFT HEIGHT (M)  FOR THE SAFE DISTANCE CURVES
2000.      (2000. M = 6562 FT)
2500
ENTER A 0 OR 1
0 IF YOU WISH TO VIEW ALL RESULTS REAL-TIME.
1 TO DISCONNECT THE FILE -OUTPUT- SO THAT RESULTS MAY BE SELECTIVELY PRINTED.
0
```

```
PAGE - 1-
```

```
 WAVELENGTH (NM)                      1064.0
 BEAM DIAMETER (CM)  (1/E PT)        5.38000000
 BEAM DIVERGENCE (RAD.-FULL ANGLE)    .00026400
 PULSE ENERGY (JOULES)                .12500000
 EXPOSURE DURATION (SECONDS)        .10000000E+01
 PRF (PPS)                             30.0
 SINGLE PULSE TIME WIDTH (SECONDS) .15000000E-07
 OPTICAL AID DEVICE                  7. X 50.
 TRANSMISSIVITY OF O.A.D.             1.0000

 LASER CATEGORY-  AF CAT C

                         DATE OF RUN 19/11/81
```

Example 1 (cont'd)

SINGLE PULSE SAFE EYE EXPOSURE DISTANCES (METERS)

	OCULAR POINT	EXTENDED S.	SKIN
M.P.E. FOR .150000E-07 SECS	.500000E-05	.123311E+00	.100000E+00
O.D. AT LASER APERTURE	3.04		.00

EXTINCTION COEFFICIENT	TURBULENCE- STRONG .1000E-12	.1000E-13	.1000E-14	.1000E-15	WEAK .1000E-16
0.000 VACUUM					
UNPROTECTED EYE SEED	6554.3	6554.3	6554.3	6554.3	6554.3
EYE O D AT 2500. M	.80	.80	.80	.80	.80
UNFILTERED O.A.D. SED	47102.5	47102.5	47102.5	47102.5	47102.5
O.A.D. O D AT 2800. M	2.39	2.39	2.39	2.39	2.39
.001 PURE AIR					
UNPROTECTED EYE SEED	2628.1	5480.6	6484.0	6530.9	6532.2
EYE O D AT 2500. M	.07	.75	.79	.79	.79
UNFILTERED O.A.D. SED	8424.7	21839.2	41099.9	45836.4	46021.0
O.A.D. O D AT 2800. M	1.60	2.34	2.39	2.39	2.39
.088 VERY CLEAR					
UNPROTECTED EYE SEED	2454.6	4615.1	5155.5	5176.9	5177.5
EYE O D AT 2500. M	.00	.65	.70	.70	.70
UNFILTERED O.A.D. SED	7054.0	14545.9	19265.0	19676.7	19688.3
O.A.D. O D AT 2800. M	1.50	2.23	2.29	2.29	2.29
.120 CLEAR DAY					
UNPROTECTED EYE SEED	2398.4	4378.9	4830.7	4847.9	4848.4
EYE O D AT 2500. M	.00	.62	.66	.67	.67
UNFILTERED O.A.D. SED	6689.6	13151.1	16569.7	16920.7	16928.0
O.A.D. O D AT 2800. M	1.46	2.19	2.25	2.25	2.25
.410 LIGHT HAZE					
UNPROTECTED EYE SEED	2010.9	3105.6	3255.1	3260.0	3260.1
EYE O D AT 2500. M	.00	.30	.35	.35	.35
UNFILTERED O.A.D. SED	4765.5	7562.5	8312.5	8344.5	8345.4
O.A.D. O D AT 2800. M	1.11	1.84	1.89	1.90	1.90
1.150 HAZE					
UNPROTECTED EYE SEED	1482.9	1934.4	1970.4	1971.4	1971.5
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	3011.1	4011.5	4144.7	4149.1	4149.2
O.A.D. O D AT 2800. M	.21	.94	.99	1.00	1.00
2.550 THIN FOG					
UNPROTECTED EYE SEED	951.2	1102.9	1110.0	1110.2	1110.3
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	1742.1	2038.9	2059.9	2060.6	2060.6
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00
7.620 LIGHT FOG					
UNPROTECTED EYE SEED	527.4	557.1	558.2	558.2	558.2
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	885.3	947.1	949.7	949.8	949.8
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00
19.600 MEDIUM FOG					
UNPROTECTED EYE SEED	265.8	270.8	271.0	271.0	271.0
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	428.0	438.3	438.7	438.7	438.7
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00
78.200 THICK FOG					
UNPROTECTED EYE SEED	80.8	81.0	81.0	81.0	81.0
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	126.5	126.9	126.9	127.0	127.0
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00

Example 1 (cont'd)

MULTIPLE PULSE OCULAR POINT SAFE EYE DISTANCES (METERS)

	OCULAR POINT	EXTENDED S.	SKIN
M.P.E. FOR .100000E+01 SECS	.912871E-06	.225133E-01	.182574E-01
O.D. AT LASER APERTURE	3.78		.00

EXTINCTION COEFFICIENT	TURBULENCE- STRONG .1000E-12	.1000E-13	.1000E-14	.1000E-15	WEAK .1000E-16
0.000 VACUUM					
UNPROTECTED EYE SEED	15612.4	15612.4	15612.4	15612.4	15612.4
EYE O D AT 2500. M	1.53	1.53	1.53	1.53	1.53
UNFILTERED O.A.D. SED	110509.3	110509.3	110509.3	110509.3	110509.3
O.A.D. O D AT 2800. M	3.13	3.13	3.13	3.13	3.13
.001 PURE AIR					
UNPROTECTED EYE SEED	4433.4	10573.8	15084.6	15478.3	15490.0
EYE O D AT 2500. M	.81	1.48	1.53	1.53	1.53
UNFILTERED O.A.D. SED	13702.4	36451.0	60455.3	103385.5	104812.3
O.A.D. O D AT 2800. M	2.34	3.07	3.13	3.13	3.13
.088 VERY CLEAR					
UNPROTECTED EYE SEED	3993.7	8144.8	9890.8	9985.1	9987.8
EYE O D AT 2500. M	.71	1.39	1.44	1.44	1.44
UNFILTERED O.A.D. SED	10548.3	20997.1	28836.7	29700.2	29727.1
O.A.D. O D AT 2800. M	2.24	2.97	3.02	3.03	3.03
.120 CLEAR DAY					
UNPROTECTED EYE SEED	3860.7	7566.6	8938.3	9006.4	9008.3
EYE O D AT 2500. M	.68	1.36	1.40	1.40	1.40
UNFILTERED O.A.D. SED	9917.7	18591.4	24262.6	24783.0	24798.7
O.A.D. O D AT 2800. M	2.20	2.93	2.99	2.99	2.99
.410 LIGHT HAZE					
UNPROTECTED EYE SEED	3036.2	4854.7	5207.2	5220.0	5220.3
EYE O D AT 2500. M	.36	1.04	1.09	1.09	1.09
UNFILTERED O.A.D. SED	6432.7	9937.4	11065.5	11119.9	11121.4
O.A.D. O D AT 2800. M	1.84	2.58	2.63	2.63	2.63
1.150 HAZE					
UNPROTECTED EYE SEED	2092.2	2783.7	2854.3	2856.5	2856.5
EYE O D AT 2500. M	.00	.24	.28	.29	.29
UNFILTERED O.A.D. SED	3818.5	5039.6	5232.5	5239.1	5239.3
O.A.D. O D AT 2800. M	.94	1.68	1.73	1.73	1.73
2.950 THIN FOG					
UNPROTECTED EYE SEED	1286.2	1495.0	1507.2	1507.6	1507.6
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	2120.9	2483.2	2512.5	2513.4	2513.4
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00
7.820 LIGHT FOG					
UNPROTECTED EYE SEED	680.2	723.3	725.0	725.0	725.0
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	1050.0	1126.5	1130.0	1130.1	1130.1
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00
19.600 MEDIUM FOG					
UNPROTECTED EYE SEED	335.9	343.1	343.3	343.3	343.3
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	500.7	513.7	514.1	514.1	514.1
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00
78.200 THICK FOG					
UNPROTECTED EYE SEED	100.7	101.0	101.0	101.0	101.0
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	146.6	147.1	147.2	147.2	147.2
O.A.D. O D AT 2800. M	.00	.00	.00	.00	.00

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SINGLE PULSE AIR-TO-GROUND SAFE DISTANCES

EGLIN AND MIDLATITUDE, SUMMER-CLEAR DAY ATMOSPHERIC CONDITIONS

	AFOSH DATA (1972)		STANDARD (1980)		EGLIN SUMMER (1980)	
ALT KM	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	5171.8	15836.3	5940.6	29351.4	5943.5	29402.4
1.0	5537.4	23484.9	6124.3	32994.0	6125.5	33019.4
2.0	5774.6	26659.8	6253.2	36148.1	6254.1	36171.3
3.0	5939.7	29337.1	6320.9	38079.0	6321.7	38100.1
4.0	6052.5	31470.6	6359.4	39281.1	6359.9	39299.2
5.0	6130.2	33126.3	6385.8	40157.5	6386.2	40173.4
6.0	6186.6	34442.1	6405.7	40848.3	6406.1	40862.6
7.0	0.0	35508.9	0.0	41426.9	0.0	41439.3
8.0	0.0	36377.9	0.0	41921.0	0.0	41931.9
9.0	0.0	37087.9	0.0	42355.0	0.0	42364.6
10.0	0.0	37712.5	0.0	42722.0	0.0	42730.5
11.0	0.0	38242.0	0.0	43034.5	0.0	43042.2
12.0	0.0	38701.8	0.0	43303.7	0.0	43310.8
13.0	0.0	39105.5	0.0	43538.0	0.0	43544.8
14.0	0.0	39467.2	0.0	43743.7	0.0	43750.4
15.0	0.0	39792.0	0.0	43925.7	0.0	43932.0
16.0	0.0	40087.3	0.0	44088.2	0.0	44094.1
17.0	0.0	40355.8	0.0	44234.2	0.0	44239.9
18.0	0.0	40601.0	0.0	44366.8	0.0	44372.1
19.0	0.0	40829.5	0.0	44487.8	0.0	44492.9
20.0	0.0	41048.4	0.0	44599.1	0.0	44604.0

NOTE- ZERO SED INDICATES NO GROUND INTERCEPT.

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SINGLE PULSE AIR-TO-GROUND SAFE DISTANCES

EGLIN SEASONAL ATMOSPHERIC CONDITIONS

	WINTER		SPRING		FALL	
ALT KM	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	5943.8	29408.9	5940.6	29351.1	5940.4	29348.4
1.0	6123.9	32985.7	6123.0	32963.5	6125.3	33014.4
2.0	6252.8	36137.7	6251.9	36112.8	6253.9	36167.9
3.0	6320.6	38070.1	6319.8	38044.9	6321.6	38098.0
4.0	6359.2	39273.0	6358.4	39249.3	6359.9	39298.5
5.0	6385.6	40150.6	6384.9	40128.7	6386.2	40173.4
6.0	6405.5	40844.1	6405.0	40822.1	6406.1	40864.2
7.0	0.0	41421.5	0.0	41403.7	0.0	41439.4
8.0	0.0	41915.8	0.0	41899.6	0.0	41931.9
9.0	0.0	42349.8	0.0	42335.2	0.0	42364.5
10.0	0.0	42716.9	0.0	42703.4	0.0	42730.4
11.0	0.0	43029.5	0.0	43017.1	0.0	43041.9
12.0	0.0	43298.7	0.0	43286.9	0.0	43310.2
13.0	0.0	43533.1	0.0	43521.9	0.0	43544.0
14.0	0.0	43738.9	0.0	43728.0	0.0	43749.2
15.0	0.0	43920.9	0.0	43910.5	0.0	43930.8
16.0	0.0	44083.4	0.0	44073.0	0.0	44092.8
17.0	0.0	44229.5	0.0	44219.6	0.0	44238.4
18.0	0.0	44362.1	0.0	44352.5	0.0	44370.7
19.0	0.0	44483.3	0.0	44474.1	0.0	44491.6
20.0	0.0	44594.8	0.0	44585.9	0.0	44602.7

NOTE- ZERO SED INDICATES NO GROUND INTERCEPT.

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MULTIPLE PULSE AIR-TO-GROUND SAFE DISTANCES

EGLIN AND MIDLATITUDE, SUMMER-CLEAR DAY ATMOSPHERIC CONDITIONS

	AFOSH DATA (1972)		STANDARD (1980)		EGLIN SUMMER (1980)	
ALT KM	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	9970.2	29631.5	12699.9	49708.9	12711.7	49328.5
1.0	11176.4	37015.3	13481.6	58734.0	13486.5	58801.4
2.0	12044.6	43641.1	14071.0	67497.4	14075.1	67566.1
3.0	12696.7	49676.6	14396.2	73415.4	14399.4	73482.1
4.0	13168.6	54834.2	14585.9	77355.1	14588.6	77417.3
5.0	13507.8	59082.5	14718.3	80369.9	14720.6	80426.2
6.0	13761.5	62632.3	14819.6	82846.6	14821.6	82897.4
7.0	13957.7	65638.7	14901.8	84977.7	14903.5	85024.0
8.0	14111.0	68177.2	14970.5	86855.6	14972.0	86897.3
9.0	14234.4	70354.2	15029.8	89545.0	[illegible]	85555.7
10.0	14335.4	72255.2	15079.1	90012.4	15080.3	90046.5
11.0	14422.4	73865.0	15120.5	91284.7	15121.5	91316.3
12.0	14495.6	75424.8	15155.7	92399.4	15156.6	92429.2
13.0	14558.8	76766.5	15186.1	93385.2	15187.0	93414.1
14.0	14614.3	77995.0	15212.4	94262.5	15213.3	94290.9
15.0	14614.4	79097.4	15235.6	95048.3	15236.4	95075.6
16.0	0.0	80124.1	0.0	95757.2	0.0	95783.4
17.0	0.0	81070.2	0.0	95401.6	0.0	96426.3
18.0	0.0	81945.8	0.0	96991.0	0.0	97015.1
19.0	0.0	82771.7	0.0	97534.0	0.0	97557.3
20.0	0.0	83572.2	0.0	98037.1	0.0	98060.1

NOTE- ZERO SED INDICATES NO GROUND INTERCEPT.

MULTIPLE PULSE AIR-TO-GROUND SAFE DISTANCES

EGLIN SEASONAL ATMOSPHERIC CONDITIONS

	WINTER		SPRING		FALL	
ALT KM	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	12713.2	49843.7	12699.8	49708.2	12699.2	49702.0
1.0	13479.9	58712.4	13475.4	58653.8	13485.5	58788.6
2.0	14069.3	67466.9	14064.9	67394.1	14074.6	67556.0
3.0	14394.5	73386.4	14390.3	73306.1	14399.0	73475.3
4.0	14584.6	77328.8	14580.9	77248.1	14588.5	77414.1
5.0	14717.2	80345.8	14714.0	80268.9	14720.6	80426.0
6.0	14818.7	82824.6	14815.9	82752.5	14821.6	82898.0
7.0	14901.0	84957.4	14899.4	84930.2	14903.5	85024.3
8.0	14969.8	86835.1	14967.6	86773.3	14972.0	66897.1
9.0	15029.2	88497.0	15027.1	88470.2	15031.1	88555.7
10.0	15078.5	89991.7	15076.6	89937.8	15080.3	90046.2
11.0	15119.8	91263.9	15118.2	91212.9	15121.5	91315.4
12.0	15155.1	92378.4	15153.5	92329.6	15156.6	92427.0
13.0	15185.4	93364.4	15184.0	93316.9	15186.8	93410.4
14.0	15211.8	94241.9	15210.4	94195.4	15213.1	94286.1
15.0	15235.0	95027.5	15233.6	94981.6	15236.2	95070.1
16.0	0.0	95736.2	0.0	95891.0	0.0	95777.3
17.0	0.0	96380.6	0.0	96336.3	0.0	96420.2
18.0	0.0	96970.4	0.0	96927.6	0.0	97008.7
19.0	0.0	97514.1	0.0	97472.4	0.0	97551.0
20.0	0.0	98018.1	0.0	97977.7	0.0	98053.7

NOTE- ZERO SED INDICATES NO GROUND INTERCEPT.

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SINGLE PULSE SAFE DISTANCE CURVES FOR HEIGHT OF 2500.0 M

EGLIN AND MIDLATITUDE, SUMMER-CLEAR DAY ATMOSPHERIC CONDITIONS

	AFOSH DATA (1972)		STANDARD (1980)		EGLIN SUMMER (1980)	
DEFL ANG DEG	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	6441.2	21000.0	6464.9	21000.0	6465.1	21000.0
15.0	6438.9	21000.0	6462.6	21000.0	6462.8	21000.0
30.0	6431.3	21000.0	6454.9	21000.0	6455.1	21000.0
45.0	6415.2	21000.0	6440.1	21000.0	6440.4	21000.0
60.0	6385.0	21000.0	6413.1	21000.0	6413.5	21000.0
75.0	6324.8	40690.2	6345.9	44511.2	6346.6	44515.5
90.0	6315.3	31290.4	6390.6	40314.8	6391.1	40333.4
105.0	6096.8	-9659.3	6365.2	-9659.3	6365.8	-9659.3
120.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0
135.0	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5
150.0	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8
165.0	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2
180.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0

NOTE- TERMINATION OF THE BEAM BY GROUND INTERSECTION IS
INDICATED BY A NEGATIVE SED.
SEDS ARE ALSO TERMINATED AT A 21 KM CEILING.

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SINGLE PULSE SAFE DISTANCE CURVES FOR HEIGHT OF 2500.0 M

EGLIN SEASONAL ATMOSPHERIC CONDITIONS

	WINTER		SPRING		FALL	
DEFL ANG DEG	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	6464.8	21000.0	6464.3	21000.0	6465.1	21000.0
15.0	6462.5	21000.0	6462.1	21000.0	6462.9	21000.0
30.0	6454.7	21000.0	6454.2	21000.0	6455.2	21000.0
45.0	6439.9	21000.0	6439.3	21000.0	6440.4	21000.0
60.0	6412.8	21000.0	6412.1	21000.0	6413.6	21000.0
75.0	6345.4	44505.9	6344.3	44494.8	6346.6	44515.4
90.0	6390.2	40301.2	6389.4	40272.7	6391.1	40332.5
105.0	6364.8	-9659.3	6364.0	-9659.3	6365.7	-9659.3
120.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0
135.0	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5
150.0	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8
165.0	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2
180.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0

NOTE- TERMINATION OF THE BEAM BY GROUND INTERSECTION IS
INDICATED BY A NEGATIVE SED.
SEDS ARE ALSO TERMINATED AT A 21 KM CEILING.

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MULTIPLE PULSE SAFE DISTANCE CURVES FOR HEIGHT OF 2500.0 M

EGLIN AND MIDLATITUDE, SUMMER-CLEAR DAY ATMOSPHERIC CONDITIONS

	AFOSH DATA (1972)		STANDARD (1980)		EGLIN SUMMER (1980)	
DEFL ANG DEG	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	15221.7	21000.0	15373.7	21000.0	15374.1	21000.0
15.0	15214.5	21000.0	15366.6	21000.0	15367.0	21000.0
30.0	15190.9	21000.0	15342.8	21000.0	15343.3	21000.0
45.0	15144.8	21000.0	15292.6	21000.0	15293.1	21000.0
60.0	15051.4	21000.0	15185.4	21000.0	15186.2	21000.0
75.0	14795.9	21000.0	14934.4	21000.0	14936.3	21000.0
90.0	14358.4	21000.0	14741.7	21000.0	14744.5	21000.0
105.0	-9659.3	-9659.3	-9659.3	-9659.3	-9659.3	-9659.3
120.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0
135.0	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5
150.0	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8
165.0	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2
180.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0

NOTE- TERMINATION OF THE BEAM BY GROUND INTERSECTION IS
INDICATED BY A NEGATIVE SED.
SEDS ARE ALSO TERMINATED AT A 21 KM CEILING.

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MULTIPLE PULSE SAFE DISTANCE CURVES FOR HEIGHT OF 2500.0 M

EGLIN SEASONAL ATMOSPHERIC CONDITIONS

DEFL ANG DEG	WINTER NAKED EYE SED M	CLEAR OAD SED M	SPRING NAKED EYE SED M	CLEAR OAD SED M	FALL NAKED EYE SED M	CLEAR OAD SED M
0.0	15373.1	21000.0	15372.0	21000.0	15374.0	21000.0
15.0	15366.0	21000.0	15364.8	21000.0	15366.9	21000.0
30.0	15342.2	21000.0	15341.0	21000.0	15343.2	21000.0
45.0	15291.9	21000.0	15290.5	21000.0	15293.1	21000.0
60.0	15184.7	21000.0	15182.8	21000.0	15186.4	21000.0
75.0	14933.3	21000.0	14929.7	21000.0	14936.6	21000.0
90.0	14739.7	21000.0	14735.5	21000.0	14744.4	21000.0
105.0	-9659.3	-9659.3	-9659.3	-9659.3	-9659.3	-9659.3
120.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0	-5000.0
135.0	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5	-3535.5
150.0	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8	-2886.8
165.0	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2	-2588.2
180.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0	-2500.0

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  NOTE- TERMINATION OF THE BEAM BY GROUND INTERSECTION IS
        INDICATED BY A NEGATIVE SED.
        SEDS ARE ALSO TERMINATED AT A 21 KM CEILING.
   STOP
    36500 MAXIMUM EXECUTION FL.
    1.575 CP SECONDS EXECUTION TIME.
COMMAND- files
--LOCAL FILES--
 *DATAFL   *SEED4    $INPUT    $OUTPUT
  SEDINP    TAPE10
```

Example 2

Example 2 illustrates a method of utilizing the input constants file SEDINP, which was generated by the execution of SEED4 in example 1. After making the desired changes - in this case, requesting the calculation of a distance (line 230) for an O.D. of 2.39 (line 240) - the program may be executed without utilizing the interactive feature.

Note that:

1. The corrected file is saved on the CDC operating system as NEXT.
2. The file SEDINP and the plot tape, TAPE10, are returned prior to execution.
3. The program file, SEED4, must be rewound.
4. The OUTPUT file is disconnected.
5. The input constants file NEXT must follow the execution command, SEED4. (SEED4,NEXT)

```
COMMAND- editor
..e,sedinp,s
..l,a


   110=  .106400E+04          WAVELENGTH
   120=  .539000E+01          BEAM DIAM.
   130=  .284000E-03          DIVERGENCE
   140=  .125000E+00          POWER
   150=  .100000E+01          DURATION
   160=  .300000E+02          PRF
   170=  .150000E-07          PULSEWIDTH
   180= 1                     OD-DIS SEL
   190=  .250000E+04          DISTANCE
   200=  .700000E+01          MAG O.A.D.
   210=  .500000E+02          DIAM O.A.D
   220=  .100000E+01          XMIS O.A.D
   230= 1                     OAD OD-DIS
   240=  .280000E+04          OAD DIST
   250=  .250000E+04          A-C HEIGHT
   260= 0                     OUTPUT C-D
../1/=/2/,230
        1 CHANGE(S)
..d,240
..a,240
   240=2.39/,
ADD WONT REPLACE OR BYPASS LINES.
..l,240
   240=2.
..d,240
..a,240
   240=  2.39
ADD WONT REPLACE OR BYPASS LINES.
..s,next,o,n
..b
COMMAND- return,sedinp,tape10
COMMAND- rewind,seed4,
```

```
COMMAND- discont,output
COMMAND- seed4,next
     STOP
      36200 MAXIMUM EXECUTION FL.
      1.227 CP SECONDS EXECUTION TIME.
COMMAND- page,output
Ready..
= 1-


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  WAVELENGTH (NM)                    1054.0
  BEAM DIAMETER (CM)  (1/E PT)       5.38000000
  BEAM DIVERGENCE (RAD.-FULL ANGLE)   .00026400
  PULSE ENERGY (JOULES)               .12500000
Line    64
+

  EXPOSURE DURATION (SECONDS)       .10000000E+01
  PRF (PPS)                           30.0
  SINGLE PULSE TIME WIDTH (SECONDS) .15000000E-07
  OPTICAL AID DEVICE               7. X 50.
  TRANSMISSIVITY OF O.A.D.           1.0000


  LASER CATEGORY-  AF CAT C

                            DATE OF RUN 19/11/81

Line    75
```

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SINGLE PULSE SAFE EYE EXPOSURE DISTANCES (METERS)

	OCULAR POINT	EXTENDED S.	SKIN
M.P.E. FOR .150000E-07 SECS	.500000E-05	.123311E+00	.100000E+00
O.D. AT LASER APERTURE	3.04		.00

EXTINCTION COEFFICIENT	TURBULENCE- STRONG				WEAK
	.1000E-12	.1000E-13	.1000E-14	.1000E-15	.1000E-16

Line 88

+

0.000 VACUUM					
UNPROTECTED EYE SEED	6554.3	6554.3	6554.3	6554.3	6554.3
EYE O D AT 2500. M	.80	.80	.80	.80	.80
UNFILTERED O.A.D. SED	47102.5	47102.5	47102.5	47102.5	47102.5
RANGE FOR 2.39 O.A.D. OD	2816.	2816.	2816.	2816.	2816.
.001 PURE AIR					
UNPROTECTED EYE SEED	2628.1	5460.6	6484.0	6530.9	6532.2
EYE O D AT 2500. M	.07	.75	.79	.79	.79
UNFILTERED O.A.D. SED	8424.7	21839.2	41099.9	45836.4	46021.0
RANGE FOR 2.39 O.A.D. OD	1533.	2634.	2805.	2811.	2811.

Line 99

+

.098 VERY CLEAR					
UNPROTECTED EYE SEED	2454.6	4615.1	5155.5	5176.9	5177.5
EYE O D AT 2500. M	.00	.65	.70	.70	.70
UNFILTERED O.A.D. SED	7054.0	14545.9	19285.0	19976.7	19968.3
RANGE FOR 2.39 O.A.D. OD	1464.	2377.	2497.	2501.	2501.
.120 CLEAR DAY					
UNPROTECTED EYE SEED	2399.4	4378.9	4830.7	4647.9	4848.4
EYE O D AT 2500. M	.00	.62	.66	.67	.67
UNFILTERED O.A.D. SED	6689.6	13151.1	16699.7	16920.7	16928.0
RANGE FOR 2.39 O.A.D. OD	1441.	2299.	2406.	2409.	2409.
.410 LIGHT HAZE					

Line 110

+

UNPROTECTED EYE SEED	2010.9	3105.6	3255.1	3260.0	3260.1
EYE O D AT 2500. M	.00	.30	.35	.35	.35
UNFILTERED O.A.D. SED	4765.5	7562.5	8312.5	8344.5	8345.4
RANGE FOR 2.39 O.A.D. OD	1268.	1809.	1657.	1659.	1859.
1.150 HAZE					
UNPROTECTED EYE SEED	1462.9	1934.4	1970.4	1971.4	1971.5
EYE O D AT 2500. M	.00	.00	.00	.00	.00
UNFILTERED O.A.D. SED	3011.1	4011.5	4144.7	4149.1	4149.2
RANGE FOR 2.39 O.A.D. OD	994.	1244.	1259.	1260.	1260.
2.950 THIN FOG					
UNPROTECTED EYE SEED	961.2	1102.9	1110.0	1110.2	1110.3

```
Line   121
+ EYE     0 D AT  2500. M          .00        .00        .00        .00        .00
  UNFILTERED O.A.D. SED          1742.1     2038.9     2059.9     2060.6     2060.6
  RANGE FOR  2.39 O.A.D. OD        680.       765.       768.       768.       768.
                7.820 LIGHT FOG
  UNPROTECTED EYE SEED            527.4      557.1      558.2      558.2      558.2
  EYE     0 D AT  2500. M          .00        .00        .00        .00        .00
  UNFILTERED O.A.D. SED           885.3      947.1      949.7      949.8      949.8
  RANGE FOR  2.39 O.A.D. OD        389.       408.       408.       408.       408.
               19.600 MEDIUM FOG
  UNPROTECTED EYE SEED            265.8      270.8      271.0      271.0      271.0
  EYE     0 D AT  2500. M          .00        .00        .00        .00        .00
Line   132
+ UNFILTERED O.A.D. SED           428.0      438.3      438.7      438.7      438.7
  RANGE FOR  2.39 O.A.D. OD        201.       204.       204.       204.       204.
               78.200 THICK FOG
  UNPROTECTED EYE SEED             80.8       81.0       81.0       81.0       81.0
  EYE     0 [illegible]  2500. M   .00        .00        .00        .00        .00
  UNFILTERED O.A.D. SED           126.5      126.9      126.9      127.0      127.0
  RANGE FOR  2.39 O.A.D. OD         62.        62.        62.        62.        62.
1

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Line   143
e
```

Example 3

The purpose of Example 3 is to illustrate the output produced by SEED4 for a CW laser. Note that prior to execution all extraneous files have been returned, and that file OUTPUT has been connected so that the interactive feature of the program may be utilized.

```
COMMAND- files
--LOCAL FILES--
  NEXT     *DATAFL   *SEED4    $INPUT     OUTPUT
  LAZRCOF   TAPE10    SEDINP
COMMAND- returnx,seed4,        ,input,output
COMMAND- connect,output
COMMAND- rewindx
COMMAND- seed4
LASER SEED MATRIX COMPUTATION PROGRAM

   ENTRY OF ALL VALUES MAY BE DECIMAL OR EXPONENTIAL, AND MAY
   BE LOCATED ANYWHERE ON THE LINE.   THE EXAMPLE VALUES ARE
   NOT DEFAULT VALUES, WHICH MEANS THAT AN ENTRY IS REQUIRED
   FOR EACH QUERY.

TYPE IN THE LASER MODEL

WAVELENGTH (NANOMTRS.)
1064.
632.8
BEAM DIAMETER (CM)
2.5
7.07e-2
BEAM DIVERGENCE (RAD.-FULL ANG.)
.000264
7.07e-4
LASER POWER (JOULES)
0.11
.00075
EXPOSURE DURATION (SEC.)
1.0
.25
PRF  (PPS)
8.0
0.
SINGLE PULSE TIME (SEC) (0.0E-15 FOR C.W. LASERS)
.23E-07
0.0e-15
ENTER A 1 OR 2
 1 CALCULATES THE O D REQUIRED FOR A GIVEN DISTANCE.
 2 CALCULATES THE SAFE DISTANCE FOR A GIVEN O D.
1
DISTANCE (M) FROM LASER TO VIEWER
1000.
10
MAGNIFICATION OF THE OPTICAL AID DEVICE. (0.0 IF NONE)
7.
0
ENTER AN AIRCRAFT HEIGHT (M)  FOR THE SAFE DISTANCE CURVES
2000.     (2000. M = 6562 FT)
2000
ENTER A 0 OR 1
0 IF YOU WISH TO VIEW ALL RESULTS REAL-TIME.
1 TO DISCONNECT THE FILE -OUTPUT- SO THAT RESULTS MAY BE SELECTIVELY PRINTED.
0
```

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CW LASER

WAVELENGTH (NM)	632.8
BEAM DIAMETER (CM) (1/E PT)	.07070000
BEAM DIVERGENCE (RAD.-FULL ANGLE)	.00070700
PULSE ENERGY (JOULES)	.00075000
EXPOSURE DURATION (SECONDS)	.25000000E+00
PRF (PPS)	0.0
SINGLE PULSE TIME WIDTH (SECONDS)	0.
OPTICAL AID DEVICE	0. X 0.
TRANSMISSIVITY OF O.A.D.	0.0000

THIS IS A CW LASER.

LASER CATEGORY- AF CAT C

DATE OF RUN 19/11/81

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SINGLE PULSE SAFE EYE EXPOSURE DISTANCES (METERS)

	OCULAR POINT	EXTENDED S.	SKIN
M.P.E. FOR .250000E+00 SECS	.636396E-03	.629961E+01	.777817E+00
O.D. AT LASER APERTURE	.49		.00

EXTINCTION COEFFICIENT		TURBULENCE- STRONG .1000E-12	.1000E-13	.1000E-14	.1000E-15	WEAK .1000E-16
0.000 VACUUM						
UNPROTECTED EYE SEED		16.3	16.3	16.3	16.3	16.3
EYE O D AT	10. M	.39	.39	.39	.39	.39
.014 PURE AIR						
UNPROTECTED EYE SEED		16.3	16.3	16.3	16.3	16.3
EYE O D AT	10. M	.39	.39	.39	.39	.39
.078 VERY CLEAR						
UNPROTECTED EYE SEED		16.3	16.3	16.3	16.3	16.3
EYE O D AT	10. M	.39	.39	.39	.39	.39
.391 CLEAR DAY						
UNPROTECTED EYE SEED		16.3	16.3	16.3	16.3	16.3
EYE O D AT	10. M	.39	.39	.39	.39	.39
.954 LIGHT HAZE						
UNPROTECTED EYE SEED		16.2	16.2	16.2	16.2	16.2
EYE O D AT	10. M	.39	.39	.39	.39	.39
1.960 HAZE						
UNPROTECTED EYE SEED		16.1	16.1	16.1	16.1	16.1
EYE O D AT	10. M	.39	.39	.39	.39	.39
3.910 THIN FOG						
UNPROTECTED EYE SEED		15.8	15.8	15.8	15.8	15.8
EYE O D AT	10. M	.38	.38	.38	.38	.38
7.820 LIGHT FOG						
UNPROTECTED EYE SEED		15.3	15.3	15.3	15.3	15.3
EYE O D AT	10. M	.36	.36	.36	.36	.36
19.600 MEDIUM FOG						
UNPROTECTED EYE SEED		14.1	14.1	14.1	14.1	14.1
EYE O D AT	10. M	.31	.31	.31	.31	.31
78.200 THICK FOG						
UNPROTECTED EYE SEED		10.6	10.6	10.6	10.6	10.6
EYE O D AT	10. M	.06	.06	.06	.06	.06

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SINGLE PULSE AIR-TO-GROUND SAFE DISTANCES

EGLIN AND MIDLATITUDE, SUMMER-CLEAR DAY ATMOSPHERIC CONDITIONS

	AFOSH DATA (1972)		STANDARD (1980)		EGLIN SUMMER (1980)	
ALT KM	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	0.0	0.0	0.0	0.0	0.0	0.0
3.0	0.0	0.0	0.0	0.0	0.0	0.0
4.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	0.0	0.0	0.0	0.0	0.0	0.0
6.0	0.0	0.0	0.0	0.0	0.0	0.0
7.0	0.0	0.0	0.0	0.0	0.0	0.0
8.0	0.0	0.0	0.0	0.0	0.0	0.0
9.0	0.0	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0	0.0
11.0	0.0	0.0	0.0	0.0	0.0	0.0
12.0	0.0	0.0	0.0	0.0	0.0	0.0
13.0	0.0	0.0	0.0	0.0	0.0	0.0
14.0	0.0	0.0	0.0	0.0	0.0	0.0
15.0	0.0	0.0	0.0	0.0	0.0	0.0
16.0	0.0	0.0	0.0	0.0	0.0	0.0
17.0	0.0	0.0	0.0	0.0	0.0	0.0
18.0	0.0	0.0	0.0	0.0	0.0	0.0
19.0	0.0	0.0	0.0	0.0	0.0	0.0
20.0	0.0	0.0	0.0	0.0	0.0	0.0

NOTE- ZERO SED INDICATES NO GROUND INTERCEPT.

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SINGLE PULSE AIR-TO-GROUND SAFE DISTANCES

EGLIN SEASONAL ATMOSPHERIC CONDITIONS

	WINTER		SPRING		FALL	
ALT KM	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0	0.0	0.0	0.0	0.0	0.0	0.0
3.0	0.0	0.0	0.0	0.0	0.0	0.0
4.0	0.0	0.0	0.0	0.0	0.0	0.0
5.0	0.0	0.0	0.0	0.0	0.0	0.0
6.0	0.0	0.0	0.0	0.0	0.0	0.0
7.0	0.0	0.0	0.0	0.0	0.0	0.0
8.0	0.0	0.0	0.0	0.0	0.0	0.0
9.0	0.0	0.0	0.0	0.0	0.0	0.0
10.0	0.0	0.0	0.0	0.0	0.0	0.0
11.0	0.0	0.0	0.0	0.0	0.0	0.0
12.0	0.0	0.0	0.0	0.0	0.0	0.0
13.0	0.0	0.0	0.0	0.0	0.0	0.0
14.0	0.0	0.0	0.0	0.0	0.0	0.0
15.0	0.0	0.0	0.0	0.0	0.0	0.0
16.0	0.0	0.0	0.0	0.0	0.0	0.0
17.0	0.0	0.0	0.0	0.0	0.0	0.0
18.0	0.0	0.0	0.0	0.0	0.0	0.0
19.0	0.0	0.0	0.0	0.0	0.0	0.0
20.0	0.0	0.0	0.0	0.0	0.0	0.0

NOTE- ZERO SED INDICATES NO GROUND INTERCEPT.

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SINGLE PULSE SAFE DISTANCE CURVES FOR HEIGHT OF 2000.0 M

EGLIN AND MIDLATITUDE, SUMMER-CLEAR DAY ATMOSPHERIC CONDITIONS

	AFOSH DATA (1972)		STANDARD (1980)		EGLIN SUMMER (1980)	
DEFL ANG DEG	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	15.9	0.0	16.3	0.0	16.3	0.0
15.0	15.9	0.0	16.3	0.0	16.3	0.0
30.0	15.9	0.0	16.3	0.0	16.3	0.0
45.0	15.8	0.0	16.3	0.0	16.3	0.0
60.0	15.6	0.0	16.3	0.0	16.3	0.0
75.0	14.9	0.0	16.3	0.0	16.3	0.0
90.0	16.4	0.0	16.3	0.0	16.3	0.0
105.0	16.3	0.0	16.3	0.0	16.3	0.0
120.0	16.3	0.0	16.3	0.0	16.3	0.0
135.0	16.3	0.0	16.3	0.0	16.3	0.0
150.0	16.3	0.0	16.3	0.0	16.3	0.0
165.0	16.3	0.0	16.3	0.0	16.3	0.0
180.0	16.3	0.0	16.3	0.0	16.3	0.0

NOTE- TERMINATION OF THE BEAM BY GROUND INTERSECTION IS INDICATED BY A NEGATIVE SED.
SEDS ARE ALSO TERMINATED AT A 21 KM CEILING.

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SINGLE PULSE SAFE DISTANCE CURVES FOR HEIGHT OF 2000.0 M

EGLIN SEASONAL ATMOSPHERIC CONDITIONS

	WINTER		SPRING		FALL	
DEFL ANG DEG	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M	NAKED EYE SED M	CLEAR OAD SED M
0.0	16.3	0.0	16.3	0.0	16.3	0.0
15.0	16.3	0.0	16.3	0.0	16.3	0.0
30.0	16.3	0.0	16.3	0.0	16.3	0.0
45.0	16.3	0.0	16.3	0.0	16.3	0.0
60.0	16.3	0.0	16.3	0.0	16.3	0.0
75.0	16.3	0.0	16.3	0.0	16.3	0.0
90.0	16.3	0.0	16.3	0.0	16.3	0.0
105.0	16.3	0.0	16.3	0.0	16.3	0.0
120.0	16.3	0.0	16.3	0.0	16.3	0.0
135.0	16.3	0.0	16.3	0.0	16.3	0.0
150.0	16.3	0.0	16.3	0.0	16.3	0.0
165.0	16.3	0.0	16.3	0.0	16.3	0.0
180.0	16.3	0.0	16.3	0.0	16.3	0.0

NOTE- TERMINATION OF THE BEAM BY GROUND INTERSECTION IS INDICATED BY A NEGATIVE SED.
SEDS ARE ALSO TERMINATED AT A 21 KM CEILING.

STOP
35200 MAXIMUM EXECUTION FL.
.652 CP SECONDS EXECUTION TIME.

Example 4

Example 4 shows the Intercom commands methodology necessary to execute program SEED4 twice, and produce safe distance curve plots from program LSDC1.

(Revised 07/02/81)
(Revised 03/01/82)

```
COMMAND- ATTACH,DATAFL,ID=EN,PW=                              Example 4
 AT CY= 001
COMMAND- BEGIN,GET,DATAFL,LAZRCOF
 AT CY= 014
  UPDATE COMPLETE.
COMMAND-
COMMAND- ATTACH,SEED4,ID=XY,PW=
 AT CY= 001
COMMAND- CONNECT,INPUT,OUTPUT
COMMAND- SEED4
LASER SEED MATRIX COMPUTATION PROGRAM

   ENTRY OF ALL VALUES MAY BE DECIMAL OR EXPONENTIAL, AND MAY
   BE LOCATED ANYWHERE ON THE LINE.   THE EXAMPLE VALUES ARE
   NOT DEFAULT VALUES, WHICH MEANS THAT AN ENTRY IS REQUIRED
   FOR EACH QUERY.

TYPE IN THE LASER MODEL
 TEST CASE FOR SAFE DISTANCE CURVE PLOTS
WAVELENGTH (NANOMTRS.)
1064.
1064.
BEAM DIAMETER (CM)
2.5
2.5
BEAM DIVERGENCE (RAD.-FULL ANG.)
.000264
.264E-3
LASER POWER (JOULES)
0.11
.11
EXPOSURE DURATION (SEC.)
1.0
.25
PRF  (PPS)
8.0
8.
SINGLE PULSE TIME (SEC) (0.0E-15 FOR C.W. LASERS)
.23E-07
.23E-07
ENTER A 1 OR 2
 1 CALCULATES THE O D REQUIRED FOR A GIVEN DISTANCE.
 2 CALCULATES THE SAFE DISTANCE FOR A GIVEN O D.
1
DISTANCE (M) FROM LASER TO VIEWER
1000.
1500.
MAGNIFICATION OF THE OPTICAL AID DEVICE. (0.0 IF NONE)
7.
0
ENTER AN AIRCRAFT HEIGHT (M)  FOR THE SAFE DISTANCE CURVES
2000.      (2000. M = 6562 FT)
2000.
ENTER A 0 OR 1
0 IF YOU WISH TO VIEW ALL RESULTS REAL-TIME.
1 TO DISCONNECT THE FILE -OUTPUT- SO THAT RESULTS MAY BE SELECTIVELY PRINTED.
```

```
1
     STOP
      36300 MAXIMUM EXECUTION FL.
      0.561 CP SECONDS EXECUTION TIME.
COMMAND- FILES
--LOCAL FILES--
  TAPE10    *DATAFL    LAZRCOF  *SEED4    $INPUT
  OUTPUT    SEDINP
COMMAND- REWIND,TAPE10,LAZRCOF,SEED4,SEDINP
COMMAND- RETURN,INPUT,DATAFL
COMMAND- COPYCF,TAPE10,TAPE25
COMMAND- RETURN,TAPE10
COMMAND- EDITOR
..E,SEDINP,S
..L,A


   100= TEST CASE FOR SAFE DISTANCE CURVE PLOTS
   110=  .106400E+04          WAVELENGTH
   120=  .250000E+01          BEAM DIAM.
   130=  .264000E-03          DIVERGENCE
   140=  .110000E+00          POWER
   150=  .250000E+00          DURATION
   160=  .800000E+01          PRF
   170=  .230000E-07          PULSEWIDTH
   180= 1                     OD-DIS SEL
   190=  .150000E+04          DISTANCE
   200= 0.                    MAG O.A.D.
   210=  .200000E+04          A-C HEIGHT
   220= 1                     OUTPUT C-D
../.250000E+00/=/1./,150,V
   150=  1.           DURATION
Y
         1 CHANGE(S)
../.800000E+01/=/20./,160,V
   160=  20.           PRF
Y
         1 CHANGE(S)
..S,SECOND,O,N
..B
COMMAND- RETURN,SEDINP
COMMAND- FILES
--LOCAL FILES--
  SECOND    LAZRCOF  *SEED4     OUTPUT    TAPE25
COMMAND- SEED4,SECOND
     STOP
      36500 MAXIMUM EXECUTION FL.
      0.536 CP SECONDS EXECUTION TIME.
COMMAND- FILES
--LOCAL FILES--
  SEDINP    TAPE10    SECOND    LAZRCOF  *SEED4
  OUTPUT    TAPE25
COMMAND- COPYCF,TAPE10,TAPE25
```


(Revised 07/02/81)
(Revised 03/01/82)

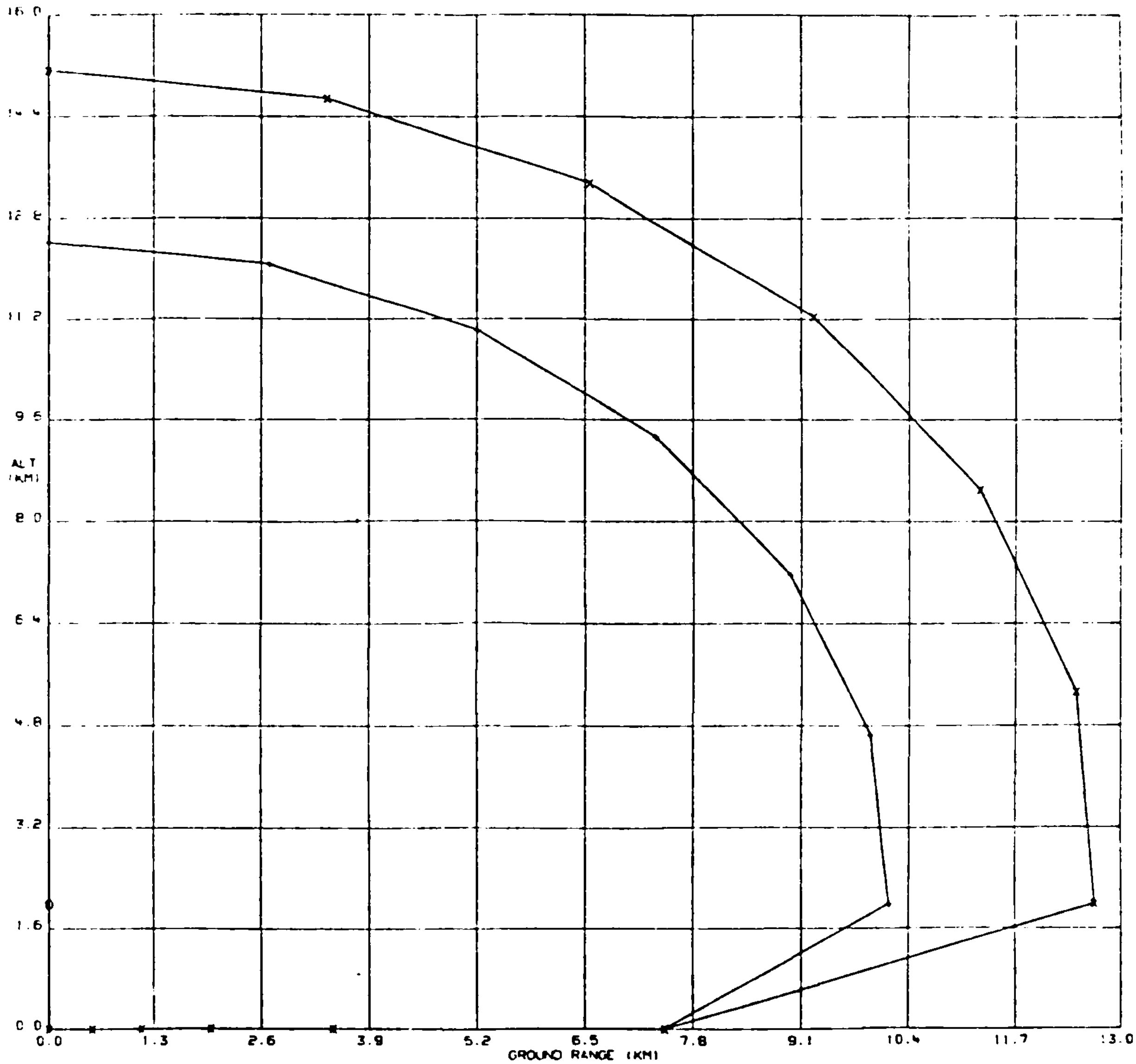
```
COMMAND- REWIND,TAPE25
COMMAND-  ATTACH,LSDC1,ID=XY,PW=
  AT CY= 001
 COMMAND- CONNECT,INPUT,
 COMMAND- DISPOSE,OUTPUT,PR=CU1
 COMMAND- CONNECT,OUTPUT
 COMMAND- LSDC1



 LASER SAFE DISTANCE CURVE PLOT PROGRAM (RUN# 1):

 ENTER PLOT TITLE AND UP TO 3 LEGEND DISCRIPTERS (MAX OF 70 CHARACTERS EACH).
 ENTER TITLE (ENTER STOP TO END PROGRAM)
 ? TEST CASE FOR LASER SAFE DISTANCE CURVE PLOTS
    TITLE=  TEST CASE FOR LASER SAFE DISTANCE CURVE PLOTS
 ENTER LEGEND(1) (ENTER 0, IF NOT APPLICABLE)
 ?PRF IS EIGHT
    LEGEND(1)= PRF IS EIGHT
 ENTER LEGEND(2) (ENTER 0, IF NOT APPLICABLE)
 ?PRF IS TWENTY
    LEGEND(2)= PRF IS TWENTY
 ENTER LEGEND(3) (ENTER 0, IF NOT APPLICABLE)
 ?0
    LEGEND(3)= 0
 ENTER ATMOSPHERE MODEL NUMBER TO BE PLOTTED (1-6)
 ?2
    ATMOSPHERE MODEL NUMBER= 2
 ENTER TYPE OF PULSE (1=SINGLE, 2=MULTIPLE, AND 3=CW)
 ?2
    TYPE OF PULSE= 2
 ENTER VIEWING TYPE (1=NAKED EYE AND 2=OAD)
 ?1
    VIEWING TYPE= 1
 LASER SAFE DISTANCE CURVE PLOT PROGRAM (RUN# 2):

 ENTER PLOT TITLE AND UP TO 3 LEGEND DISCRIPTERS (MAX OF 70 CHARACTERS EACH).
 ENTER TITLE (ENTER STOP TO END PROGRAM)
 ?STOP
    TITLE= STOP
      STOP
       37600 MAXIMUM EXECUTION FL.
       0.154 CP SECONDS EXECUTION TIME.
  FRAMES SC4020          0000000000000004
  SC4020 RECORDS         0000000000000002
  4020 ROUTINE, ERRORS DETECTED
  =ERRLNV     0000000000000002
  =PLOTV      0000000000000002
 COMMAND- FILES
 --LOCAL FILES--
   SEDINP   TAPE10    SECOND    LAZRCOF  *SEED4
   TAPE25   *LSDC1    FILMPL
 COMMAND- DISPOSE,FILMPL,FL=CU1
```



TEST CASE FOR LASER SAFE DISTANCE CURVE PLOTS

* = PRF IS EIGHT
X = PRF IS TWENTY

WEATHER MODEL IS STANDARD 1980
PULSE TYPE IS MULTIPLE
VIEWING TYPE IS NAKED EYE
LASER ALTITUDE IS 2000.0 M. = 0

(Revised 03/01/82)

TABLE 1. PROTECTION STANDARD FOR DETERMINING A MAXIMUM PERMISSIBLE EXPOSURE (MPE) FOR OCULAR EXPOSURE TO POINT SOURCES.

Wavelength, λ (nm)	Exposure duration, t (sec)	Protection standard (J/cm^2)*
$200 \leq \lambda \leq 302.4$	$10^{-2} \leq t \leq 6.05\times10^{5}$	3×10^{-3}
$302.4 < \lambda < 311.25$	$10^{-2} \leq t \leq 6.05\times10^{5}$	$10^{(0.2\ \lambda - 63)}$
$311.25 \leq \lambda < 315$	$10^{-2} \leq t < T1$	$0.56t^{1/4}$
	$T1 \leq t \leq 6.05\times10^{5}$	$10^{(0.2\ \lambda - 63)}$
$315 \leq \lambda < 400$	$10^{-9} \leq t < 10$	$0.56t^{1/4}$
	$10 \leq t \leq 6.05\times10^{5}$	1
$400 \leq \lambda < 550$	$10^{-9} \leq t < 1.8\times10^{-5}$	5×10^{-7}
	$1.8\times10^{-5} \leq t < 10$	$1.8t^{3/4}\times10^{-3}$
	$10 \leq t < 10^{4}$	10^{-2}
	$10^{4} \leq t \leq 3\times10^{4}$	$t\times10^{-6}$
$550 \leq \lambda < 650$	$10^{-9} \leq t < 1.8\times10^{-5}$	5×10^{-7}
	$1.8\times10^{-5} \leq t < T2$	$1.8t^{3/4}\times10^{-3}$
	$T2 \leq t < 10^{4}$	$B\times10^{-2}$
	$10^{4} \leq t \leq 3\times10^{4}$	$Bt\times10^{-6}$
$650 \leq \lambda \leq 700$	$10^{-9} \leq t < 1.8\times10^{-5}$	5×10^{-7}
	$1.8\times10^{-5} \leq t < 10^{3}$	$1.8t^{3/4}\times10^{-3}$
	$10^{3} \leq t < T2$	3.2×10^{-4}
	$T2 \leq t < 10^{4}$	$C\times10^{-4}$
	$10^{4} \leq t \leq 3\times10^{4}$	$Ct\times10^{-8}$
$700 < \lambda \leq 1400$	$10^{-9} \leq t \leq T3$	$5D\times10^{-7}$
	$T3 < t < 10^{3}$	$1.8Et^{3/4}\times10^{-3}$
	$10^{3} \leq t \leq 3\times10^{4}$	$3.2Et\times10^{-4}$

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Table 1 (continued)

Wavelength, (nm)	Exposure duration, t (sec)	Protection standard (J/cm^2)*
$1400 < \lambda \leq 10^6$	$10^{-9} \leq t < 10^{-7}$	10^{-2}
	$10^{-7} \leq t < 10$	$0.56t^{1/4}$
	$10 \leq t \leq 3x10^4$	$0.1t$
$\lambda = 1540$	$10^{-9} \leq t < 10^{-7}$	1
	$10^{-7} \leq t \leq 10^{-6}$	$56t^{1/4}$

*For $400 \leq \lambda \leq 1400$, protection standard is based on energy into the eye through a 7 mm pupil.

$B = 1$ for $400 \leq \lambda < 550$

$10^{(0.015(\lambda - 550))}$ for $550 \leq \lambda < 650$

$C = 3.2xT2$

$D = 10^{(\lambda - 700)/360)}$ for $700 \leq \lambda < 1060$

10 for $1060 \leq \lambda \leq 1400$

$E = 1$ for $400 \leq \lambda < 700$

$10^{((\lambda - 700)/515)}$ for $700 \leq \lambda < 1060$

5 for $1060 \leq \lambda \leq 1400$

$T1 = 0.01x10^{(0.8(\lambda - 311.25))}$ for $311.25 \leq \lambda < 315$

$T2 = 10x10^{(0.02(\lambda - 550))}$ for $550 \leq \lambda \leq 700$

$T3 = 1.8x10^{-5}x10^{(1.13x10^{-3}(\lambda - 700))}$ for $700 \leq \lambda < 1060$

$4.6x10^{-5}$ for $1060 \leq \lambda \leq 1400$

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TABLE 2. PROTECTION STANDARD FOR DETERMINING A MAXIMUM PERMISSIBLE EXPOSURE (MPE) FOR OCULAR EXPOSURE TO EXTENDED SOURCES.

Wavelength, (nm)	Exposure duration, t (sec)	Protection standard ($J/cm^2 sr$)
$200 \leq \lambda < 400$	$10^{-9} \leq t \leq 6.05 \times 10^5$	*
$400 \leq \lambda < 550$	$10^{-9} \leq t < 10$	$10t^{1/3}$
	$10 \leq t < 10^4$	21
	$10^4 \leq t \leq 3 \times 10^4$	$2.1t \times 10^{-3}$
$550 \leq \lambda < 650$	$10^{-9} \leq t < 10$	$10t^{1/3}$
	$10 \leq t < T2$	$3.83t^{3/4}$
	$T2 \leq t < 10^4$	21B
	$10^4 \leq t \leq 3 \times 10^4$	$2.1Bt \times 10^{-3}$
$650 \leq \lambda \leq 700$	$10^{-9} \leq t < 10$	$10t^{1/3}$
	$10 \leq t < 10^3$	$3.83t^{3/4}$
	$10^3 \leq t < T2$	0.64t
	$T2 \leq t < 10^4$	F
	$10^4 \leq t \leq 3 \times 10^4$	$Ft \times 10^{-4}$
$700 < \lambda \leq 1400$	$10^{-9} < t < 10$	$10Et^{1/3}$
	$10 \leq t < 10^3$	$3.83Et^{3/4}$
	$10^3 \leq t \leq 3 \times 10^4$	0.64Et
$1400 < \lambda \leq 10^6$	$10^{-9} \leq t \leq 3 \times 10^4$	*
$\lambda = 1540$	$10^{-9} \leq t \leq 10^{-6}$	*

*Use ocular point source standard of Table 1.
B, E, and T2 are as defined in Table 1.
F = 0.64xT2

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TABLE 3. PROTECTION STANDARD FOR DETERMINING A MAXIMUM PERMISSIBLE EXPOSURE (MPE) FOR SKIN.

Wavelength, λ (nm)	Exposure duration, t (sec)	Protection standard (J/cm^2)
$200 \le \lambda < 400$	$10^{-9} \le t \le 6.05 \times 10^5$	*
$400 \le \lambda \le 1400$	$10^{-9} \le t \le 10^{-7}$	$2 \times 10^{-2} E$
	$10^{-7} < t \le 10$	$1.1 t^{1/4} E$
	$10 < t \le 3 \times 10^4$	$0.2 t E$
$1400 < \lambda \le 10^6$	$10^{-9} \le t \le 3 \times 10^4$	*
$\lambda = 1540$	$10^{-9} \le t \le 10^{-6}$	*

*Use ocular point source standards of Table 1.
E is defined in Table 1.

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TABLE 4. LIMITING ANGULAR SUBTENSE

Exposure duration, t (sec)	α_{min} (mrad)
10^{-9}	8.0
10^{-8}	5.4
10^{-7}	3.7
10^{-6}	2.5
10^{-5}	1.7
10^{-4}	2.2
10^{-3}	3.6
10^{-2}	5.7
10^{-1}	9.2
1	15.0
10 or greater	24.0

The following equations can be used to generate values of α_{min} given the exposure duration:

Exposure duration	α_{min}
$10^{-9} \leq t < 1.8\times10^{-5}$ sec	$\alpha_{min} = 0.244t^{-0.168}$mrad
$1.8\times10^{-5} \leq t \leq 10$ sec	$\alpha_{min} = 14.9t^{0.207}$mrad
$t > 10$ sec	$\alpha_{min} = 24$ mrad

Sources with angles greater than α_{min} should be treated as extended sources.

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(Revised 03/01/82)

TABLE 5. EFFECTIVE EXPOSURE DURATIONS AND CONVERSION FACTORS FOR DETERMINING THE MPE FOR MULTIPLE PULSE EXPOSURES

The multiple pulse MPE equals the least of: the MPE based on the pulsewidth criteria or the MPE based on the pulse train criteria. The MPE is the product of the appropriate conversion factor and the protection standards (Tables 1, 2 and 3) which correspond to the applicable exposure duration given below.

Wavelength, λ (nm)	Pulsewidth, PW (sec)	Pulse Separation, PS (sec)
$200 \leq \lambda < 400$	$10^{-2} \leq PW$	$PS < 6.05 \times 10^5$
		$6.05 \times 10^5 \leq PS$
$400 \leq \lambda < 1060$	$10^{-9} \leq PW \leq 10^{-5}$	$PS < 0.004$
		$0.004 \leq PS < 1.0$
		$1.0 \leq PS$
	$10^{-5} < PW \leq 1.0$	$PS < 1.0$
		$1.0 \leq PS$
	$1.0 < PW$	$PS < 2 \times 10^3$
		$2 \times 10^3 \leq PS$
$1060 \leq \lambda \leq 10^6$	$10^{-9} \leq PW \leq 10^{-5}$	$PS < 0.004$
		$0.004 \leq PS < 1.0$
		$1.0 \leq PS$
	$10^{-5} < PW$	$PS < 1.0$
		$1.0 \leq PS$

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(Revised 03/01/82)

Table 5 (continued)

Pulse Separation, PS (sec)	Pulsewidth, criteria		Pulse train criteria	
	*Applicable exposure duration	Conversion factor	*Applicable exposure duration	Conversion factor
$PS < 6.05 \times 10^5$	-	-	TOT	1/N
$6.05 \times 10^5 \leq PS$	PW	1.0	-	-
$PS < 0.004$	PW	0.06	TL	1/N
$0.004 \leq PS < 1.0$	PW	$PS^{0.5}$	TL	1/N
$1.0 \leq PS$	PW	1.0	-	-
$PS < 1.0$	-	-	TOT	1/N
$1.0 \leq PS$	PW	1.0	-	-
$PS < 2 \times 10^3$	-	-	TOT	1/N
$2 \times 10^3 \leq PS$	PW	1.0	-	-
$PS < 0.004$	PW	0.06	TL	1/N
$0.004 \leq PS < 1.0$	PW	$PS^{0.5}$	TL	1/N
$1.0 \leq PS$	PW	1.0	-	-
$PS < 1.0$	-	-	TOT	1/N
$1.0 \leq PS$	PW	1.0	-	-

PS = (1/PRF) - PW for simple pulse trains. $PS^{0.5}$ is a unitless conversion factor, with PS in seconds.
PRF = Pulse repetition frequency.
TOT = Total on time. For simple periodic pulses TOT = PW x N.
N = Number of pulses in the train(s). For simple periodic pulses N = PRFx(TL-PW)+1 = PRFxTL.
TL = Length of the pulse train(s).

*Applicable exposure duration is that exposure duration to be used in determining a single exposure MPE that must be multiplied by the appropriate conversion factor to obtain the MPE, in terms of (joules/cm^2)/pulse, for a multiple pulse exposure.

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Table 6

Categorization Criteria

1. Lasers Radiating as Point Sources

Category	$200nm \leq \lambda < 400nm$	$400nm \leq \lambda \leq 700nm$
AF CAT A	$H_T \leq MPE(N)$ (Max$T_{op} \leq$ 7 days	$H_{T(PW)} \leq MPE_{PW}$
AF CAT B	None	$H_T > MPE$ (PW > 0.25sec) and $H_T \leq 2.6x10^{-3}PW$ (PW > 0.25sec)
AF CAT C	$H_T > MPE(N)$ (Max$T_{op} \leq$ 7 days and *$H \leq 10$ ($t \leq 0.25sec$) or $H \leq 40\ t_{max}$ ($t_{max} > 0.25sec$)	$H_T > MPE$ (PW $\leq$ 0.25sec) or $H_T > 2.6x10^{-3}PW$ (PW > 0.25sec) and *$H \leq 10$ ($t \leq 0.25sec$) or $H \leq 40\ t_{max}$ ($t_{max} > 0.25sec$) and $H \leq \pi\ MPE_{EXT}$ (PW $\leq$ 0.25sec) or $H \leq 25\pi\ PW$ (PW > 0.25sec)

* For radiant exposure H marked by * use total energy accumulated in 0.25sec.

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Table 6 (continued)

Category	$200nm \leq \lambda < 400nm$	$400nm \leq \lambda \leq 700nm$
AF CAT D	A point source laser is an AF CAT D laser if (a) the emission characteristics for AF CAT C lasers are exceeded but the laser does not qualify as an AF CAT E laser, (b) the emission characteristics are unknown, or (c) the MPE is unknown	
AF CAT E	A point source laser is an AF CAT E laser if $Q \geq 3x10^4$ (for $t \leq 1.5sec$) or $Q \geq 2x10^4\ t$ (for $t > 1.5sec$).	

Category	$700nm < \lambda \leq 1400nm$	$1400nm < \lambda \leq 10^6nm$
AF CAT A	$H_{T(PW)} \leq MPE_{PW}$	$H_{T(PW)} \leq MPE_{PW}$
AF CAT B	None	None
AF CAT C	$H_T > MPE_{(PW)}$ and $^*H \leq 10$ ($t \leq 0.25sec$) or $H \leq 40\ t_{max}$ ($t_{max} > 0.25sec$) and $H_{PW} \leq \pi\ MPE_{EXT}$	$H_T > MPE_{(PW)}$ and $^*H \leq 10$ ($t \leq 0.25sec$) or $H \leq 40\ t_{max}$ ($t_{max} > 0.25sec$)
AF CAT D	A point source laser is an AF CAT D laser if (a) the emission characteristics for AF CAT C laser does not qualify as an AF CAT E laser, (b) the emission characteristics are unknown, or (c) the MPE is unknown.	

*ibid

Table 6 (continued)

Category	$200nm < \lambda \leq 1400nm$	$1400nm < \lambda \leq 10^6 nm$
AF CAT E	A point source laser is an AF CAT E laser if $Q \geq 3x10^4$ (for $t \leq 1.5sec$) or $Q \geq 2x10^4\ t$ (for $t > 1.5sec$).	

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TABLE 7. ATMOSPHERIC EXTINCTION COEFFICIENTS*

Extinction Coefficients $\mu(cm^{-1})$
Midlatitude Summer - Clear Day (23 km Visibility)

	WAVELENGTH					
H(km)	337.1 nm	488.0 nm	514.5 nm	632.8 nm	694.3 nm	860 nm
0	3.22 E-6	1.95 E-6	1.83 E-6	1.46 E-6	1.96 E-6	1.07 E-6
0-1	2.39 E-6	1.35 E-6	1.26 E-6	9.85 E-7	1.40 E-6	7.18 E-7
1-2	1.39 E-6	6.69 E-7	6.15 E-7	4.58 E-7	7.10 E-7	3.22 E-7
2-3	9.68 E-7	3.62 E-7	3.23 E-7	2.21 E-7	3.63 E-7	1.45 E-7
3-4	7.51 E-7	2.33 E-7	2.03 E-7	1.25 E-7	1.92 E-7	7.49 E-8
4-5	6.42 E-7	1.83 E-7	1.57 E-7	9.19 E-8	1.19 E-7	5.08 E-8
5-6	5.64 E-7	1.53 E-7	1.31 E-7	7.39 E-8	7.96 E-8	3.92 E-8
6-7	5.01 E-7	1.33 E-7	1.13 E-7	6.32 E-8	6.11 E-8	3.27 E-8
7-8	4.54 E-7	1.23 E-7	1.05 E-7	5.91 E-8	5.30 E-8	3.12 E-8
8-9	4.12 E-7	1.14 E-7	9.70 E-8	5.59 E-8	4.77 E-8	3.02 E-8
9-10	3.72 E-7	1.04 E-7	8.92 E-8	5.20 E-8	4.35 E-8	2.85 E-8
10-11	3.35 E-7	9.51 E-8	8.17 E-8	4.81 E-8	3.98 E-8	2.68 E-8
11-12	3.03 E-7	8.79 E-8	7.59 E-8	4.55 E-8	3.75 E-8	2.60 E-8
12-13	2.74 E-7	8.11 E-8	7.04 E-8	4.30 E-8	3.55 E-8	2.50 E-8
13-14	2.43 E-7	7.33 E-8	6.38 E-8	3.95 E-8	3.28 E-8	2.34 E-8
14-15	2.14 E-7	6.58 E-8	5.76 E-8	3.64 E-8	3.04 E-8	2.19 E-8
15-16	1.89 E-7	5.89 E-8	5.17 E-8	3.32 E-8	2.79 E-8	2.04 E-8
16-17	1.69 E-7	5.36 E-8	4.74 E-8	3.10 E-8	2.62 E-8	1.94 E-8
17-18	1.51 E-7	4.93 E-8	4.38 E-8	2.92 E-8	2.50 E-8	1.87 E-8
18-19	1.33 E-7	4.35 E-8	3.87 E-8	2.61 E-8	2.23 E-8	1.67 E-8
19-20	1.15 E-7	3.54 E-8	3.14 E-8	2.09 E-8	1.78 E-8	1.33 E-8

*McClatchey, R. A., Fenn, R. W., Selby, J. E. A., Volt, F. E., and Garing, J. W. (1972) <u>Optical Properties of the Atmosphere</u> (Third Ed), AFCRL-72-0497, ERP 411.

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Table 7 (continued)

Extinction Coefficients μ (cm^{-1})
Midlatitude Summer - Clear Day (23 km Visibility)

WAVELENGTH

H(km)	1.06 μm	1.336 μm	3.392 μm	10.591 μm	27.90 μm	337.0 μm
0	8.85 E-7	6.47 E-7	1.86 E-5	3.68 E-6	3.00 E-4	2.03 E-4
0-1	5.89 E-7	4.30 E-7	1.81 E-5	3.32 E-6	3.00 E-4	1.60 E-4
1-2	2.60 E-7	1.89 E-7	1.71 E-5	1.91 E-6	3.00 E-4	9.66 E-5
2-3	1.14 E-7	8.16 E-8	1.65 E-5	1.16 E-6	3.00 E-4	5.58 E-5
3-4	5.67 E-8	3.93 E-8	1.60 E-5	7.64 E-7	3.00 E-4	2.87 E-5
4-5	3.74 E-8	2.54 E-8	1.54 E-5	5.58 E-7	3.00 E-4	1.50 E-5
5-6	2.81 E-8	1.87 E-8	1.54 E-5	4.50 E-7	3.00 E-4	7.17 E-6
6-7	3.32 E-8	1.53 E-8	1.46 E-5	3.77 E-7	3.00 E-4	3.97 E-6
7-8	2.24 E-8	1.48 E-8	1.52 E-5	3.04 E-7	2.95 E-4	2.17 E-6
8-9	2.18 E-8	1.45 E-8	1.41 E-5	2.40 E-7	1.32 E-4	1.12 E-6
9-10	2.08 E-8	1.40 E-8	1.43 E-5	1.97 E-7	5.77 E-5	5.72 E-7
10-11	1.97 E-8	1.33 E-8	1.40 E-5	1.59 E-7	2.33 E-5	2.75 E-7
11-12	1.93 E-8	1.31 E-8	1.39 E-5	1.26 E-7	5.87 E-6	8.43 E-8
12-13	1.88 E-8	1.28 E-8	1.37 E-5	9.73 E-8	1.16 E-6	2.05 E-8
13-14	1.76 E-8	1.21 E-8	1.34 E-5	8.52 E-8	2.78 E-7	5.44 E-9
14-15	1.68 E-8	1.16 E-8	1.36 E-5	8.88 E-8	1.28 E-7	2.50 E-9
15-16	1.57 E-8	1.09 E-8	1.28 E-5	8.66 E-8	8.51 E-8	1.64 E-9
16-17	1.51 E-8	1.05 E-8	1.20 E-5	8.53 E-8	6.37 E-8	1.23 E-9
17-18	1.45 E-8	1.02 E-8	1.14 E-5	8.63 E-8	4.67 E-8	9.03 E-10
18-19	1.31 E-8	9.23 E-9	1.09 E-5	8.70 E-8	3.84 E-8	7.30 E-10
19-20	1.04 E-8	7.26 E-9	1.00 E-5	9.04 E-8	3.18 E-8	5.89 E-10

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APPENDIX C

C.1 Laser Threshold Level Program, LTLP

Program LTLP is an interactive program designed to provide a quick-look estimate of the distance from a high energy laser at which a given energy density (threshold level) occurs. The distances are calculated for vacuum and clear-day (extinction coefficient of .088 um) cases only.

The mathematics utilized by program LTLP are as follows:

$$A_{be} = P_o / T_L$$

where

A_{be} is the area of the beam at the threshold level (cm^2)

P_o is the laser output power (Joules)

T_L is the user-specified energy density (J/cm^2)

and,

$$R_{cm} = \frac{(4\ A_{be}/\Pi)^{\frac{1}{2}} - db}{\tan\ \phi}$$

where

R_{cm} is the vacuum case distance (cm)

db is the beam aperture diameter (cm)

ϕ is the full angle of divergence (radians)

The sea-level calculation of distance utilizes the iterative procedure outlined in Section B.1.3 (pgs. B-20 to B-24), and employ values of .088 and 1.0 for the attenuation coefficient and maximum permissible exposure level (respectively) in those equations.

A sample execution of program LTLP follows:

```
COMMAND- CONNECT,INPUT,OUTPUT
COMMAND- ATTACH,LTLP1,ID=XY,PW=
 AT CY= 001
COMMAND- LTLP1
ENTER WAVELENGTH(NM)
?10600
ENTER BEAM DIAMETER(CM), DIVERGENCE(RAD)
?2.5,.0002
ENTER 5 LASER OUTPUT POWERS(J)
?50,100
,0,0,0
APERTURE ENERGY DENSITIES ARE-
 .101859E+02  .203718E+02 0.          0.          0.
ENTER 5 ENERGY LEVELS(J/SQCM)
?9.,15.,0,0,0

WAVELENGTH= .106000E+05
BEAM DIAMETER=  .250000E+01 DIVERGENCE=  .200000E-03


POWER OUTPUT IS  .500000E+02 JOULES-
  VACUUM CASE
     FOR A THRESHOLD LEVEL OF .900000E+01 J/SQCM, THE RANGE IS .798076E+01 MTRS.
  SEA-LEVEL, CLEAR DAY CASE
     FOR A THRESHOLD LEVEL OF .900000E+01 J/SQCM, THE RANGE IS .793435E+01 MTRS.
  VACUUM CASE
     FOR A THRESHOLD LEVEL OF .150000E+02 J/SQCM, THE RANGE IS0.           MTRS.
  SEA-LEVEL, CLEAR DAY CASE
     FOR A THRESHOLD LEVEL OF .150000E+02 J/SQCM, THE RANGE IS0.           MTRS.


POWER OUTPUT IS  .100000E+03 JOULES-
  VACUUM CASE
     FOR A THRESHOLD LEVEL OF .900000E+01 J/SQCM, THE RANGE IS .630632E+02 MTRS.
  SEA-LEVEL, CLEAR DAY CASE
     FOR A THRESHOLD LEVEL OF .900000E+01 J/SQCM, THE RANGE IS .625471E+02 MTRS.
  VACUUM CASE
     FOR A THRESHOLD LEVEL OF .150000E+02 J/SQCM, THE RANGE IS .206731E+02 MTRS.
  SEA-LEVEL, CLEAR DAY CASE
     FOR A THRESHOLD LEVEL OF .150000E+02 J/SQCM, THE RANGE IS .205416E+02 MTRS.
     STOP
      21100 MAXIMUM EXECUTION FL.
      0.057 CP SECONDS EXECUTION TIME.
```

C.1.1 Threshold Level Safe Eye Distance

If the assumptions are made that (a) the threshold level energy density is applicable to a surface that absorbs none of the transmitted radiation (100% reflectivity); (b) the surface is non-curved, and sufficiently large to surround the beam; and (c) the direction of the reflected beam is not pertinent, then program SEED4 may be used to calculate the safe eye distance from the assumed surface.

The methodology for determining this safe eye distance is as follows:

1. Calculate the power of the beam at the surface:

$$A_b = \Pi\left(\frac{db}{2}\right)^2$$

$$P_e = A_b * T_L$$

where

db = the beam diameter (cm)

A_b = area of the beam aperature (cm^2)

T_L = the user-specified energy density (J/cm^2)

2. Execute program SEED4, substituting the P_e value calculated above for the laser power.

The safe eye distances produced by SEED4, executed in this manner, indicate the distances from the assumed surface at which eyes are not hazarded. The aperture OD, printed on Page 2 of the results, denotes the optical density requirement at the assumed surface, with the stipulation that eyes protected by this OD are not directed along the laser beam.